PROJECT FOR THE DEGREE OF MASTER OF SCIENCE IN MINING ENGINEERING

DATA MINING FOR MINE-MILL ORE GRADE RECONCILIATION AT ERDENET MINING CORPORATION

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Abstract

This project investigates the relationship between the mined ore and the produced copper at the Erdenet Mining Corporation (EMC) surface copper mine in Mongolia. Four and half years of data (from 2011-2015) was obtained from the open pit mine and mineral processing plant of EMC. The mine-mill data was collected on a shift basis. The data was examined carefully using process knowledge and exploratory data analysis techniques to detect and eliminate errors. Ultimately, two years of data (2013-2014) was selected for further analysis.

As is common in all mines, the material flow between the mine and mill is complicated by numerous stockpiles. The copper grade going into a stockpile may not be directly related to the copper grade exiting a stockpile. Therefore, data mining techniques applied to detect the relationship between mined ore and milled copper had to overcome the complications introduced by the presence of stockpiles. Multiple data sets were created by aggregating the original dataset by different periods. For example, in one case, data was aggregated by three shifts, to convert the data from shift-basis to daily-basis. Aggregation is an ideal way to absorb variations in material flow (tonnage and grade) between mine and mill. Data was aggregated by 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 shifts ("aggregated widths" or AW).

Correlation analysis was then conducted on each version of the data to determine if a relationship existed between mine data and mill data. Correlation was computed for various period lengths, but not exceeding 28 days. Therefore, in a given year, several correlation plots were produced at each aggregated width. The number of times the correlation coefficient exceeded 0.8 in a year was measured. Results showed that correlation improved with aggregation width. The highest correlations occurred at AW of 7 or 8. This suggests that the stockpiles aggregate material for 2-3 days.

Correlation analysis also included examining a time shift ("lag") between mine data and mill data. This is useful to detect whether material takes a certain amount of time before it is processed and produced as copper. However, results indicated that once the data was aggregated, a time lag greater than 0 only worsened correlation.

Acronyms

EMC	Erdenet Mining Corporation LLC
DD	Development Department
DTA&CE	Department of Technology Automation and Computer Engineering
CRL	Central Research Laboratory
DOPM	Department of Open Pit Mine
DMPP	Department of Mineral Processing Plant
C&TS	Crushing and Transportation Section
MFS	Milling-Flotation Section
KKD	Ball mill line
KSI	SAG mill line
SAG	Semi-autogenous grinding
AW	Aggregate Width
N	Number of periods
PL	Period Length
BC	Block Count
$PC^{0.8}$	Peak Count with high correlation r>0.8
$PB^{0.8}$	Percentage of blocks with correlation greater than 0.8

Units of Measurement and Abbreviations

Cu	copper
Mo	molybdenum
mtpy	metric tonnes-per-year
tpy	tonnes-per-year
s.g.	specific gravity
mm	millimeter
µm	micrometer
mln.t	million tonne

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1. Introduction

This project investigates the relationship between mined ore, milled ore, and the copper that is produced at the Erdenet Mining Corporation's (EMC) surface copper mine. The mine is located in Erdenet, Mongolia.

Data was obtained from the open pit mine and mineral processing plant of EMC for the period 2011-2015. The Mineral Processing Plant (MPP) of EMC has two processing sections; one is a ball mill line and the other is a SAG mill line. The Open Pit Mine (OPM) sends the sulfide ore to the mills, while the oxidized ore is sent to the oxide ore stockpile.

The mine data was very granular (on a shovel and drill block basis). This was aggregated to convert the mine data into mine-wide data. The mill data was mostly from automated sensors and consisted of ore and tonnage from various parts of the mill.

Data mining was conducted to examine if there was a linear relationship between mined ore and the copper produced. The time delay in material flow, caused by presence of stockpiles, was examined both by aggregating data for various lengths of time, as well as explicitly by modeling the correlation between mined ore and mill ore (with a time lag).

1.1 Brief Description of Open Pit Mine

Capacity

The capacity of the EMC open pit mine is around 26-28.0 million metric-tonnes-per-year (mtpy) of ore, and will further increase to 35.0 million mtpy over the next five to six years. Initially, open pit mine capacity was 16.0 million mtpy by the Feasibility Study. In 1989, the capacity extended to 20.0 million mtpy. The mine capacity has constantly increased since 1989, as shown in Figure 1.

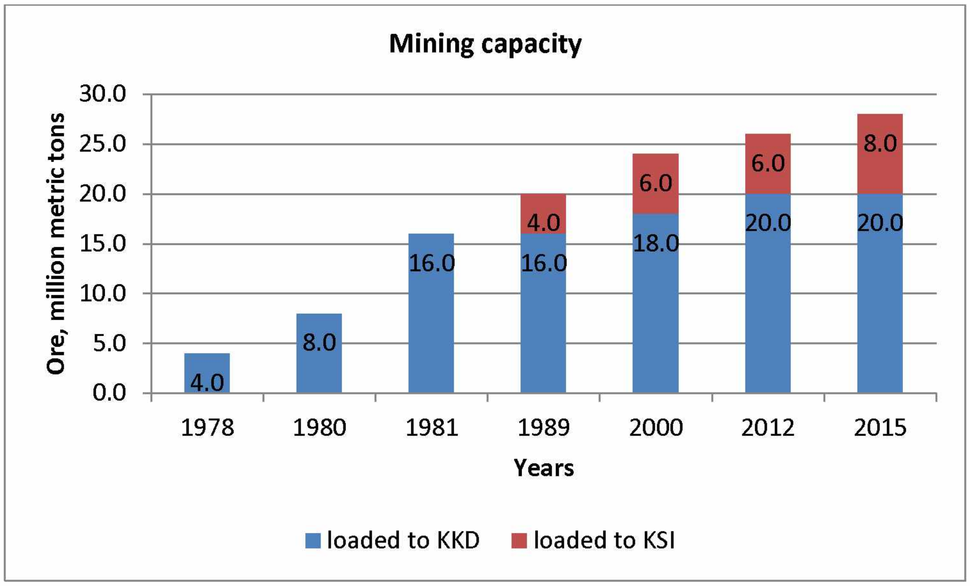

Figure 1. EMC open pit mine capacity

Ore loading to parallel processing sections

The sulfide ore material is sent to KKD and KSI, while the oxidized ore is sent to oxidized ore stockpiles shown in Figure 2. KKD consists of a line of ball mills, while KSI consists of semi-autogenous (SAG) mills. Each reports to their own flotation section.

KKD contains a gyratory crusher that accepts –1000 mm rocks, and crushes to –250mm. The product of the gyratory crusher goes to the second and third stage crushers. The product of the third stage crusher (size +6.3mm-25 mm) is milled by ball mills (size –74 µm), and then processed by four flotation sections (sections I, II, III, IV).

KSI contains a jaw crusher that also accepts –1000 mm rock and crushes to –300 mm. The product of the jaw crusher goes to the SAG mills, and then goes to the ball mills for regrinding (product size –74 µm), and then is processed by two flotation sections (sections V, VI).

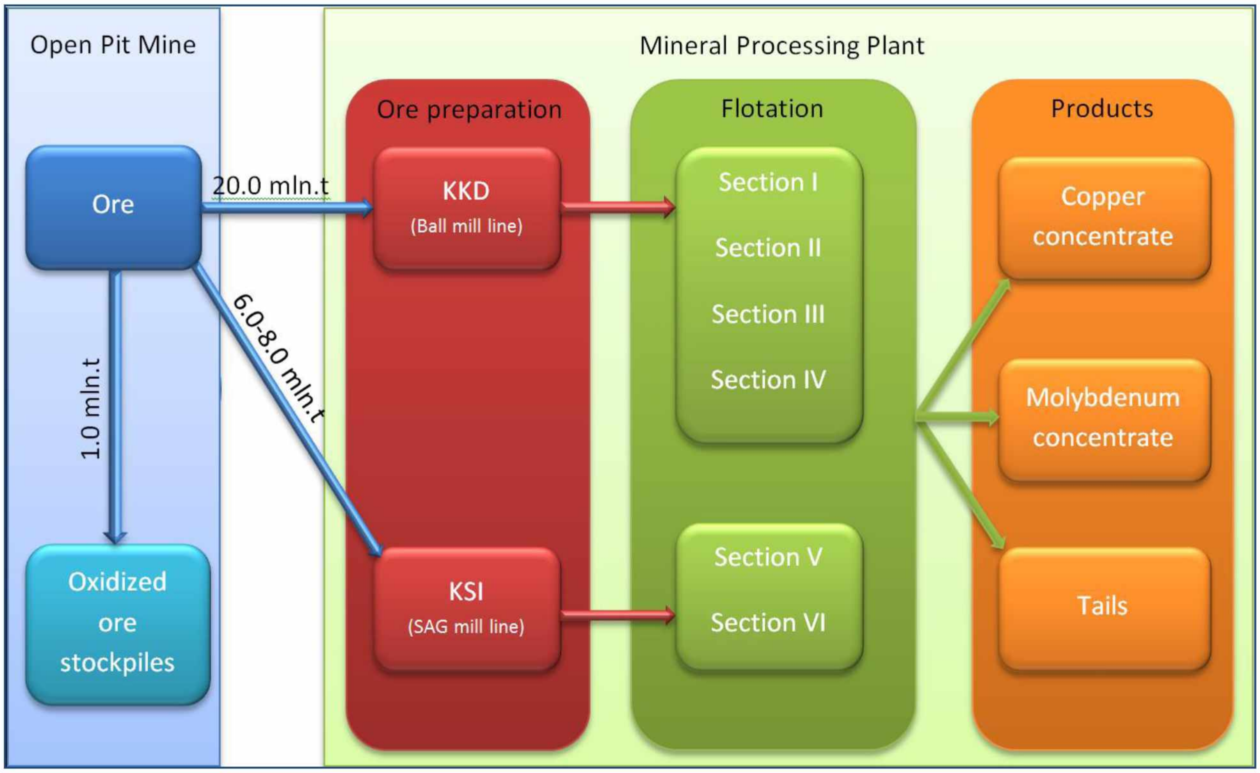

Figure 2. Simple flowsheet of ore flow

Requirements for the ore

Sulfide ore is classified as either I (primary) or II (secondary) depending on the origins of ore. The primary sulfide ore contains pyrite (FeS_2) and the secondary sulfide ore contains chalcocite (Cu_2S), bornite (Cu_5FeS_4), chalcopyrite ($CuFeS_2$) and covellite (CuS), etc.

The Mineral Processing Plant (MPP) has six parallel flotation sections, and requires I and II sulfide ore with the cut-off grade $Cu \geq 0.25\%$. MPP accepts total oxidation of ore less than 8%. If the total oxidation is more than 8%, it becomes oxidized ore, so then it is sent to the oxidized ore stockpiles.

2. Mine and Mill Data Analysis

2.1. Mine data

For the past five years, the mined ore information was collected from the mine production records. In the period 2011-2015, the material sent to KKD and KSI was recorded separately. As shown in Tables 1 and 2, the mined ore information was organized in three ways: by shift, by 10-day periods and by month. The copper (Cu) and molybdenum (Mo) grades were obtained for the mine from blasthole sampling. The MPP department obtained Cu and Mo grade values at various locations in MPP on the basis of physical samples and on-line instruments.

The ore production for each year (2011-2015) is plotted in Figures 3 through 7. The Open Pit Mine (OPM) did not load ore to the Mineral Processing Plant (MPP) every July for three shifts. This was because MPP shut down for three shifts for annual planned maintenance work.

The tonnage sent to KKD and KSI is shown in Table 2 for the second 10-day period of January 2011. The entire mine production data are in a similar format. In 2011 and 2012, the molybdenum grade was not initially recorded. In 2015, mining output was only recorded in January.

Table 1. A snapshot of mine production data.

Date	№	Receivers	Mining Output Plan								Mining Actual Output				Mining Output Control by CRL				
			Ore ('000 t)	№ Shovel	№ bench	№ block	№ rep.	$Cu_{over.}$ %	Cu_{oxid} %	$Cu_{sulf.}$ %	Ore ('000 t)	$Cu_{over.}$ %	Cu_{oxid} %	$Cu_{sulf.}$ %	Ore ('000 t)	$Cu_{over.}$ %	Cu_{oxid} %	$Cu_{sulf.}$ %	recovery,%
Jan 11, 2011	shift 1	KKD	5.2	16	1310	10158		0.600	2.5	60.0	1.2	0.630	2.7	60.0	1.2	0.450	4.0	62.2	82.6
			3.0	18	1310	10131		0.650	3.0	65.0	4.7	0.680	2.9	65.0	4.7	0.500	1.6	50.0	84.3
			4.8	19	1280	80023		0.500	2.5	75.0	6.4	0.560	2.7	75.0	6.4	0.620	1.8	72.6	87.6
			6.0	20	1295	95082 95085		0.450	2.5	60.0	7.1	0.480	2.5	60.0	7.1	0.335	1.6	71.6	88.5
			19.0	*weighted average KKD*				0.535	2.6	64.6	19.4	0.564	2.7	66.2	19.4	0.476	1.8	66.1	86.8
		KSI	2.7	18	1310	10131		0.650	3.0	65.0	2.0	0.680	2.9	65.0	2.0	0.500	1.6	50.0	84.3
			3.2	19	1280	80020 80023		0.500	2.5	75.0	3.5	0.560	2.7	75.0	3.5	0.580	1.9	72.4	87.1
			2.1	20	1295	95082 95085		0.450	2.5	60.0	2.4	0.480	2.5	60.0	2.4	0.335	1.6	71.6	88.5
			8.0	*weighted average KSI*				0.538	2.7	67.7	7.9	0.566	2.7	67.9	7.9	0.485	1.7	66.5	86.8
	Subtotal		**27.0**	**weighted average MPP**				**0.536**	**2.6**	**65.5**	**27.3**	**0.565**	**2.7**	**66.7**	**27.3**	**0.479**	**1.8**	**66.2**	**86.8**
	shift 2	KKD	4.0	18	1310	10131		0.700	3.0	65.0	3.1	0.730	2.9	65.0	3.1	0.500	1.6	50.0	84.3
			3.0	19	1280	80023		0.400	2.5	75.0	2.6	0.440	2.7	75.0	2.6	0.620	1.8	72.6	87.6
			3.0	20	1295	95082 95085		0.450	2.5	60.0	3.4	0.470	2.5	60.0	3.4	0.335	1.6	71.6	88.5
			10.0	*weighted average KKD*				0.535	2.7	66.5	9.1	0.550	2.7	66.0	9.1	0.473	1.7	64.5	86.8
		KSI																	
			0.0	*weighted average KSI*				0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.000	0.000
	Subtotal		**10.0**	**weighted average MPP**				**0.535**	**2.7**	**66.5**	**9.1**	**0.550**	**2.7**	**66.0**	**9.1**	**0.515**	**1.7**	**64.5**	**86.8**
	shift 3	KKD	4.9	18	1310	10131		0.700	3.0	60.0	5.0	0.730	2.7	60.0	5.0	0.500	1.6	50.0	84.3
			4.9	19	1280	80023		0.600	2.5	75.0	5.2	0.610	2.6	75.0	5.2	0.620	1.8	72.6	87.6
			8.2	20	1295	95082 95085		0.400	2.5	60.0	9.5	0.440	2.5	60.0	9.5	0.335	1.6	71.6	88.5
			18.0	*weighted average KKD*				0.536	2.6	64.1	19.7	0.558	2.6	64.0	19.7	0.452	1.7	66.4	87.2
		KSI																	
			0.0	*weighted average KSI*				0.000	0.0	0.0	0.0	0.000	0.0	0.0	0.0	0.000	0.0	0.0	0.0
	Subtotal		**18.0**	**weighted average MPP**				**0.536**	**2.6**	**64.1**	**19.7**	**0.558**	**2.6**	**64.0**	19.7	**0.452**	**1.7**	**66.4**	**87.2**
TOTAL			**55.0**					**0.536**	**2.6**	**65.2**	**56.1**	**0.560**	**2.6**	**65.6**	**56.1**	**0.475**	**1.7**	**66.0**	**87.0**

Table 2. In a 10-day period, mine production (actual) by KKD and KSI by shift.

Date Jan-11		Loaded Ore to KKD				Loaded Ore to KSI			
Day	*Shifts*	*Ore thous.t*	*Cu %*	*Cu oxid. %*	*Cu I sulf. %*	*Ore thous.t*	*Cu %*	*Cu oxid. %*	*Cu I sulf. %*
11	1	19.4	0.564	2.67	66.15	7.9	0.566	2.68	67.91
	2	9.1	0.550	2.69	65.98	0	0	0	0
	3	19.7	0.558	2.57	63.95	0	0	0	0
12	1	19.9	0.546	2.61	60.90	5.3	0.546	2.71	57.73
	2	17.2	0.550	2.69	59.15	0	0	0	0
	3	16.2	0.577	3.00	57.77	0	0	0	0
13	1	17.8	0.554	2.74	64.10	7.6	0.557	2.69	59.53
	2	16.8	0.575	2.74	57.76	0	0	0	0
	3	19.2	0.561	2.49	61.97	0	0	0	0
14	1	16	0.601	2.55	58.56	7.9	0.613	2.57	58.73
	2	7	0.613	2.60	67.57	0	0	0	0
	3	20.4	0.544	2.64	61.47	0	0	0	0
15	1	21.1	0.542	2.63	61.84	7.4	0.539	2.6	54.72
	2	18.9	0.564	3.34	51.34	0	0	0	0
	3	21.8	0.561	3	54.79	8.2	0.535	3.33	55.60
16	1	21.2	0.577	2.52	62.66	7.7	0.581	2.48	58.44
	2	21.7	0.559	3.26	56.12	0	0	0	0
	3	21.8	0.526	3.03	62.88	0	0	0	0
17	1	22.7	0.539	3.21	60.13	8	0.546	3.36	60.75
	2	16.4	0.520	2.96	65.09	0	0	0	0
	3	21.4	0.513	3.55	58.17	0	0	0	0
18	1	22.8	0.513	3.32	58.55	0	0	0	0
	2	9.4	0.560	3.57	51.80	7.3	0.560	3.44	53.35
	3	21.1	0.523	3.19	53.90	7.1	0.531	3.06	61.47
19	1	22.5	0.498	3.27	59.31	8	0.507	3.53	51.12
	2	19.9	0.517	2.96	56.35	0	0	0	0
	3	19.2	0.533	3.42	54.68	7.7	0.537	2.51	58.11
20	1	19.6	0.523	2.81	58.77	7	0.532	2.92	53
	2	17.4	0.517	2.94	58.21	0	0	0	0
	3	18.1	0.503	3.60	50.82	8	0.496	3.80	48.93

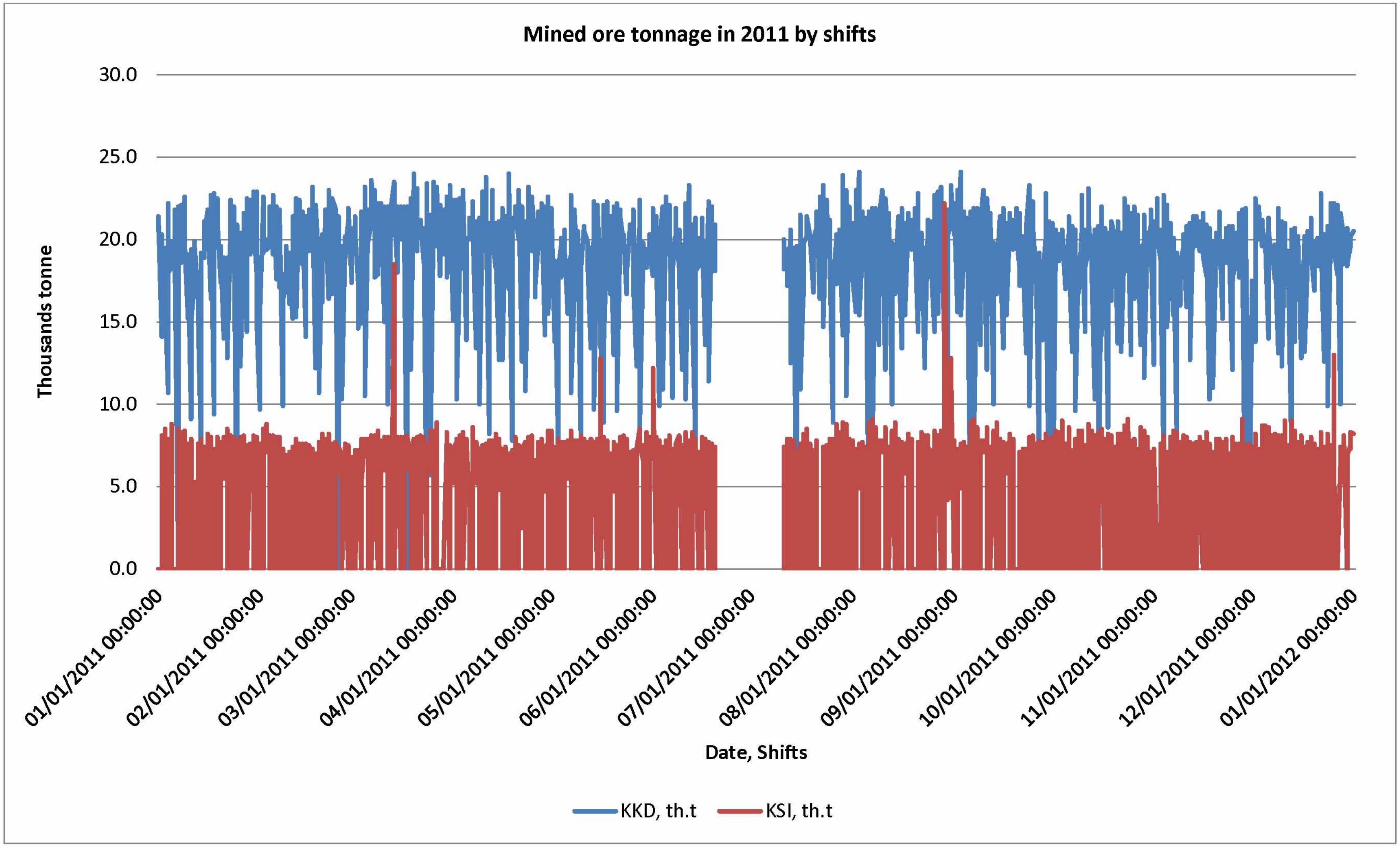

Figure 3. Mined ore tonnage in 2011 by shift

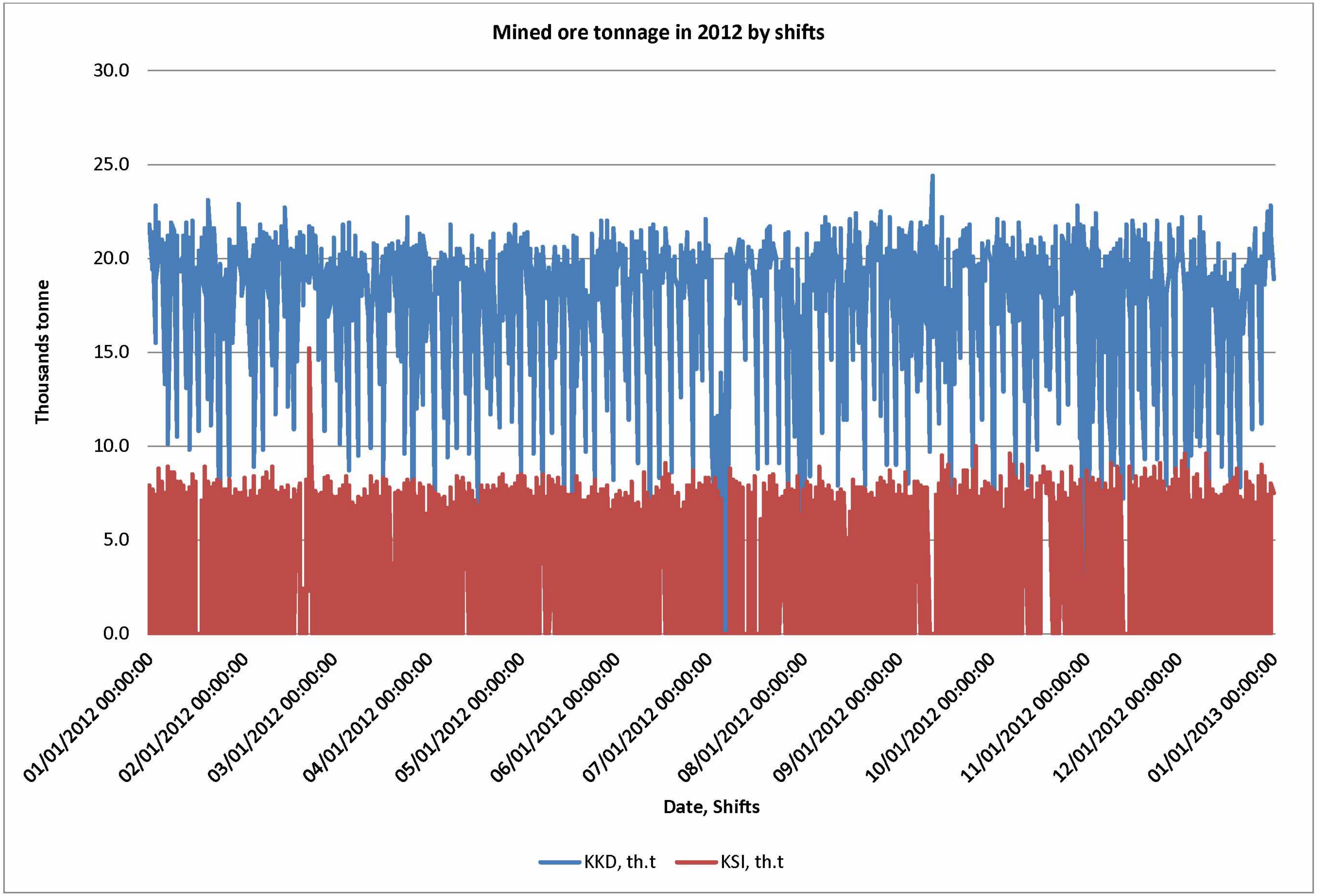

Figure 4. Mined ore tonnage in 2012 by shift

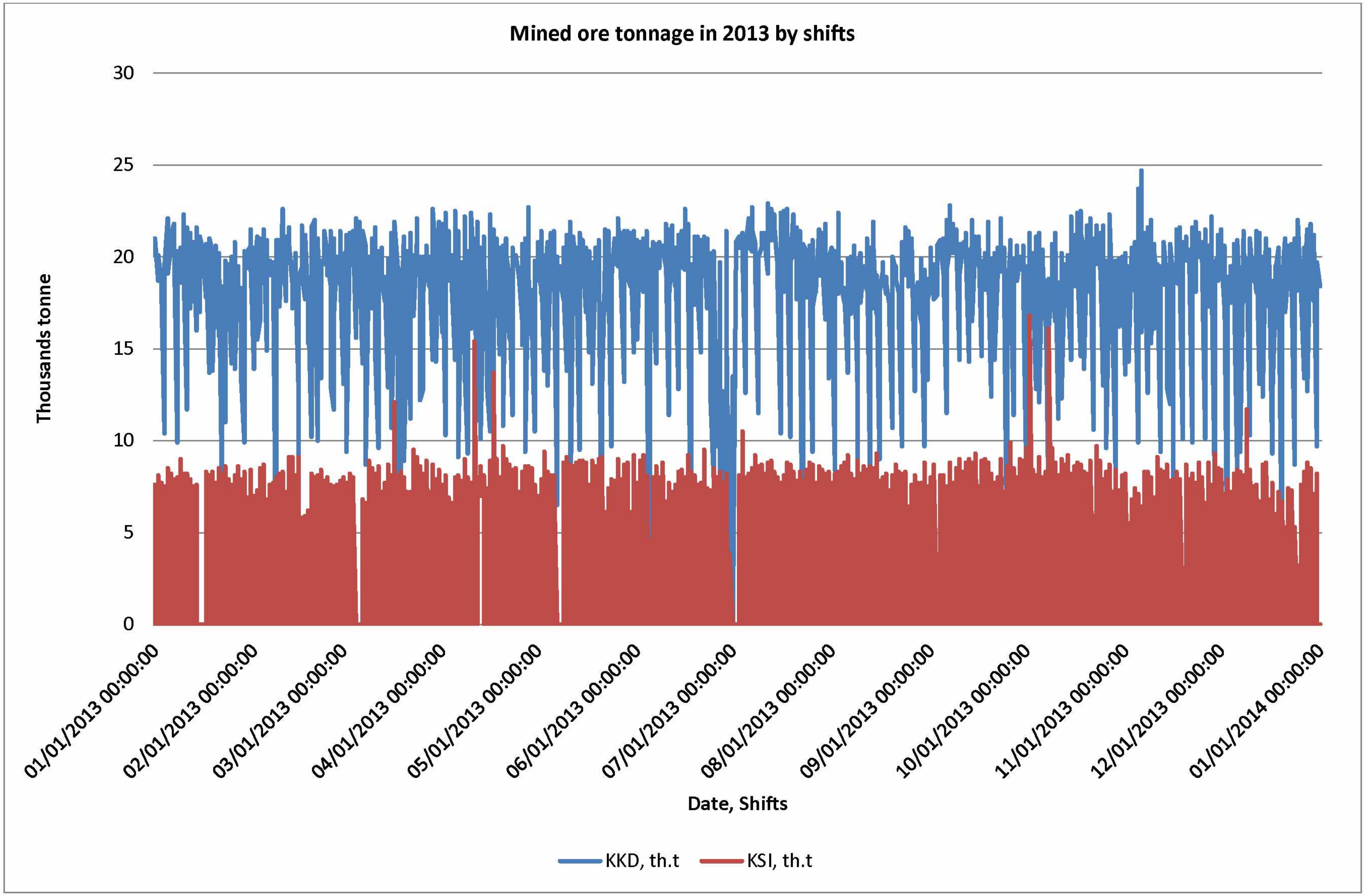

Figure 5. Mined ore tonnage in 2013 by shift

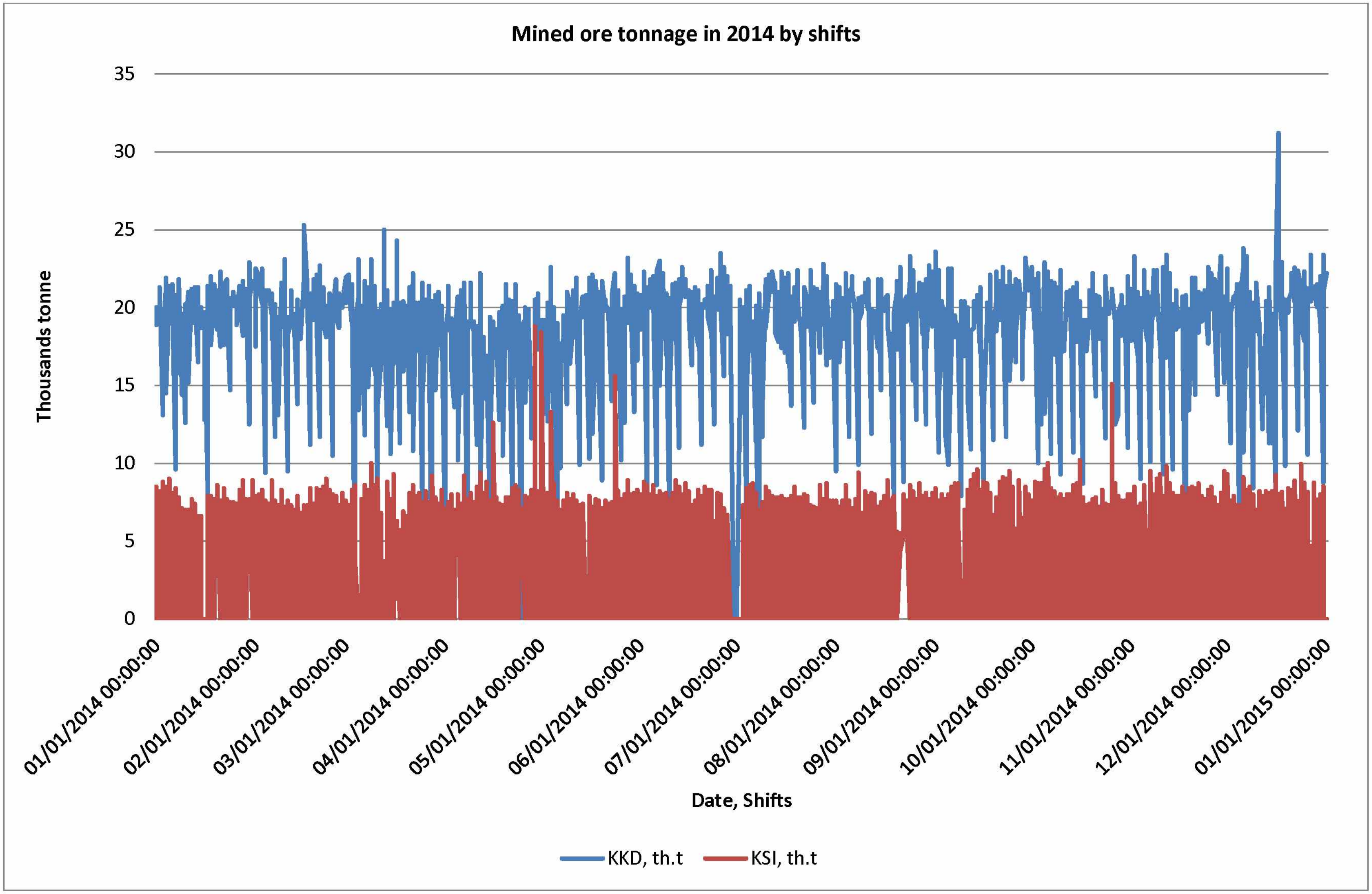

Figure 6. Mined ore tonnage in 2014 by shift

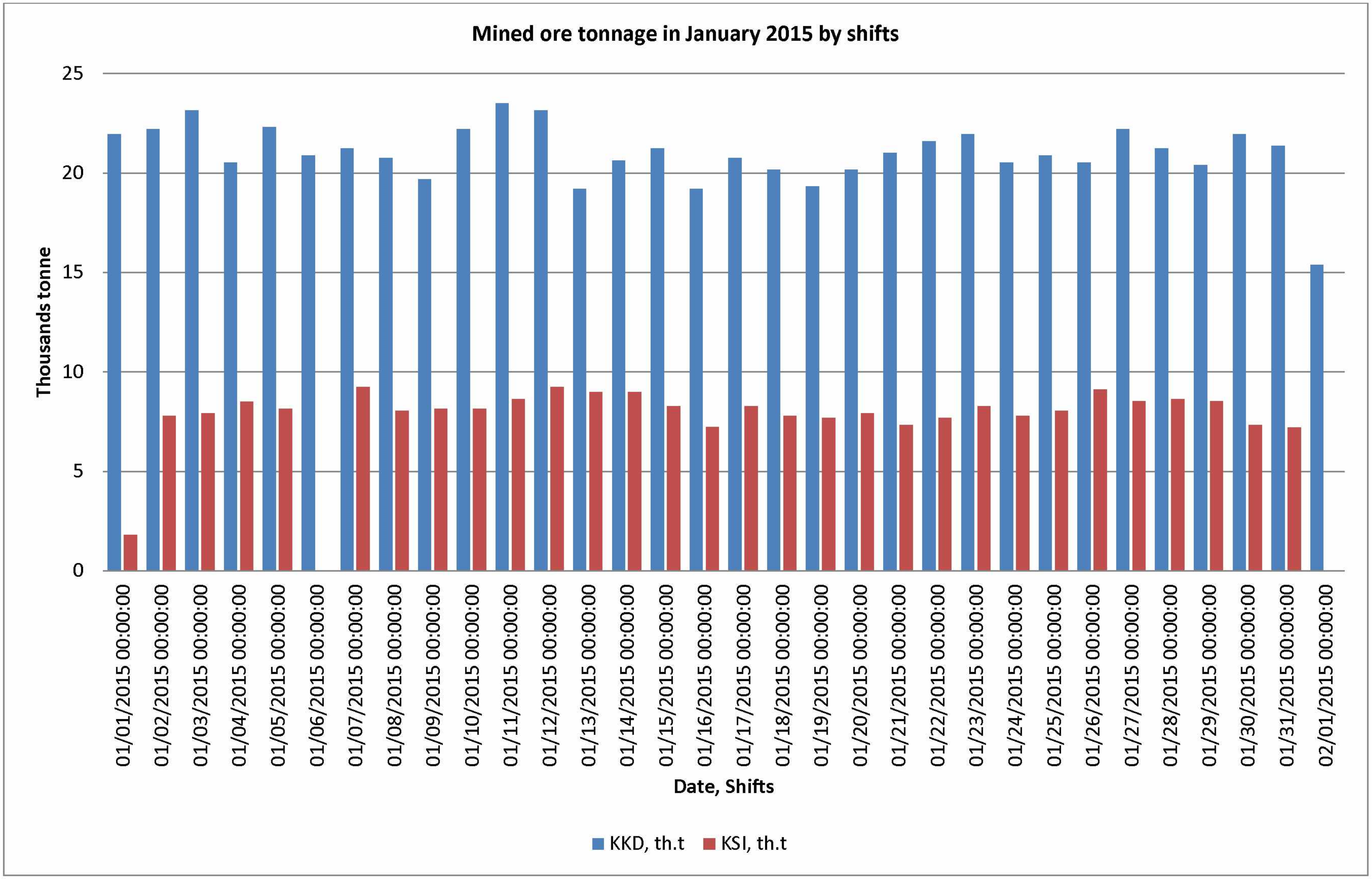

Figure 7. Mined ore tonnage in January 2015 by shift

2.2. Mill data

The mill data was collected for the same time period as the mining data (in 2011-2015).
The ore flow information came from a consolidated report (сводка) of the Department of Mineral Processing Plant. The mill data was recorded separately for KKD and KSI.

2.2.1. Data record through KKD (Ball mill line)

Ore preparation

The process of ore preparation belongs to the Crushing and Transport Section (C&TS) of MPP. The C&TS receives the –1000mm fraction of the ore material from OPM and crushes to +6.3 –25mm for the ball milling process.

The C&TS includes two gyratory crushers (ККД-1200/130ГРЩ), a stockpile of large crushed ore with a capacity of 65,000 tonnes, five pieces of second stage cone crushers (КСД-2200Т2-ДТ), a stockpile of medium crushed ore, six pieces of third stage cone crushers (КСД-3000Т2-ДП), a stockpile of small crushed ore with a capacity of 135,000 tonnes, and transporting conveyors.

In the ore preparation section, data was obtained on the following for KKD:

- "**Received ore**" by tonnage (crushed through gyratory crushers)
- "**to 1st stockpile**" of large crushed ore material by tonnage (after the gyratory crusher on the conveyor #1a, 2a)
- "**to 3rd stockpile**" of small crushed ore material by tonnage (after the third stage cone crusher on the conveyor #17)

For example, the tonnage record of ore preparation is shown in Table 3 for the first half of January 2015.

The raw data had to be prepared before it could be used for analysis. This is because different process data were collected for different time periods or units. The ore material tonnage was recorded on a tonnes-per-hour basis on the conveyors #1A and 2A. Therefore, the "**to 1st stockpile**" column was obtained by multiplying the conveyor data by 8 hours for the shift.

Tonnage on conveyor #17, on the other hand, was recorded as total tonnage for the entire 8 hours (shift). In the “Date / Shifts” column, 01/01/2015 (month/date/year) and 08:00:00, 04:00:00 and 12:00:00 express the end of the first (night), second (morning), and third (afternoon) shifts, respectively.

Table 3. A snapshot of the data record of ore preparation by KKD

Date / Shifts	Received ore KKD ,tonne	To 1st stockpile,tonne (conveyor #1A, 2A)	To 3rd stockpile, tonne (conveyor #17)
01/01/2015 08:00:00	21293	21813.00	21939.00
01/01/2015 04:00:00	19902	20923.17	19620.00
01/02/2015 12:00:00	21821	22114.38	19599.00
01/02/2015 08:00:00	20773	21871.50	20440.00
01/02/2015 04:00:00	10243	10216.53	10557.00
01/03/2015 12:00:00	21378	21828.22	23542.00
01/03/2015 08:00:00	22405	23355.14	21927.00
01/03/2015 04:00:00	20590	21064.68	20534.00
01/04/2015 12:00:00	19284	20297.50	18470.00
01/04/2015 08:00:00	20088	19853.36	21310.00
01/04/2015 04:00:00	20675	21145.06	19646.00
01/05/2015 12:00:00	11176	12076.04	13804.00
01/05/2015 08:00:00	21542	22016.95	22057.00
01/05/2015 04:00:00	19044	19673.99	20460.00
01/06/2015 12:00:00	20715	21143.86	17752.00
01/06/2015 08:00:00	20246	20939.07	21565.00
01/06/2015 04:00:00	4562	3968.30	5325.00
01/07/2015 12:00:00	19828	20790.52	23365.00
01/07/2015 08:00:00	20463	21230.55	20211.00
01/07/2015 04:00:00	20852	21079.98	21465.00
01/08/2015 12:00:00	17228	19624.57	15163.00
01/08/2015 08:00:00	20176	20319.30	20067.00
01/08/2015 04:00:00	20007	20150.39	18877.00
01/09/2015 12:00:00	14029	15251.91	16071.00
01/09/2015 08:00:00	19693	20555.09	21872.00
01/09/2015 04:00:00	9733	12961.90	9602.00
01/10/2015 12:00:00	19058	16516.43	20827.00
01/10/2015 08:00:00	21638	21609.30	22921.00
01/10/2015 04:00:00	20826	21605.04	23048.00
01/11/2015 12:00:00	21611	22223.89	20625.00
01/11/2015 08:00:00	22416	22916.58	21485.00
01/11/2015 04:00:00	20549	21890.99	20949.00
01/12/2015 12:00:00	21589	22388.40	21165.00
01/12/2015 08:00:00	22491	23122.21	21951.00
01/12/2015 04:00:00	19330	20509.12	17411.00
01/13/2015 12:00:00	13405	13667.28	12760.00
01/13/2015 08:00:00	17639	18693.81	20326.00
01/13/2015 04:00:00	8474	7959.13	8311.00
01/14/2015 12:00:00	19652	20867.42	21852.00
01/14/2015 08:00:00	20213	20689.18	21306.00
01/14/2015 04:00:00	20791	20962.64	21238.00
01/15/2015 12:00:00	17953	19459.60	19062.00
01/15/2015 08:00:00	20461	15267.34	20807.00
01/15/2015 04:00:00	16907	-	18711.00
01/16/2015 12:00:00	18179	-	19039.00

Mill and Flotation

The mill and flotation process belongs to the Milling-Flotation Section (MFS) of MPP. The MFS receives a –25mm fraction of ore material from the C&TS and grinds to –74μm for the flotation process and floats copper and molybdenum.

The MPP has six parallel sections of the technological process. The first to fourth sections relate to KKD (ball mill line).

Figure 8 shows the sampling points of the technological process MPP. For the MPP, the ore flow record uses this flowsheet. The feed record to the flotation of ore material tonnage and copper and molybdenum grades are measured on the point (p.) p.601, p.602, p.303 and p.404.

In the ore processing section, ore flow data was recorded on the following points:

- **"to ball mills"** ore tonnage:

(Small crushed ore material to the ball mills points on conveyors #19a, 19, 20, 21, 22, 23, 24, 25 and 26).

- **"to flotation"** ore tonnage and copper and molybdenum grade:

(Feed to flotation after the ball mills on the points: Section I, Feed p.601 (201)
Section II, Feed p.602 (2)
Section III, Feed p.303 (3)
Section IV, Feed p.404 (4).

For example, the tonnage and grade record of ore process is shown in Table 4 for the first half of January 2015.

The ore material tonnage was recorded hourly on the conveyors #19A to #26. Therefore, the **"to ball mills"** column was obtained by multiplying tonnage of transporting ore on conveyors #19A to #26 by 8 hours for the shift.

The **"to flotation"** column summarized tonnage of feed on the sampling points p.601, p.602, p.303 and p.404. The copper and molybdenum grades and metal tons in whole sections for first to fourth were calculated from sampling points p.601, p.602, p.303 and p.404.

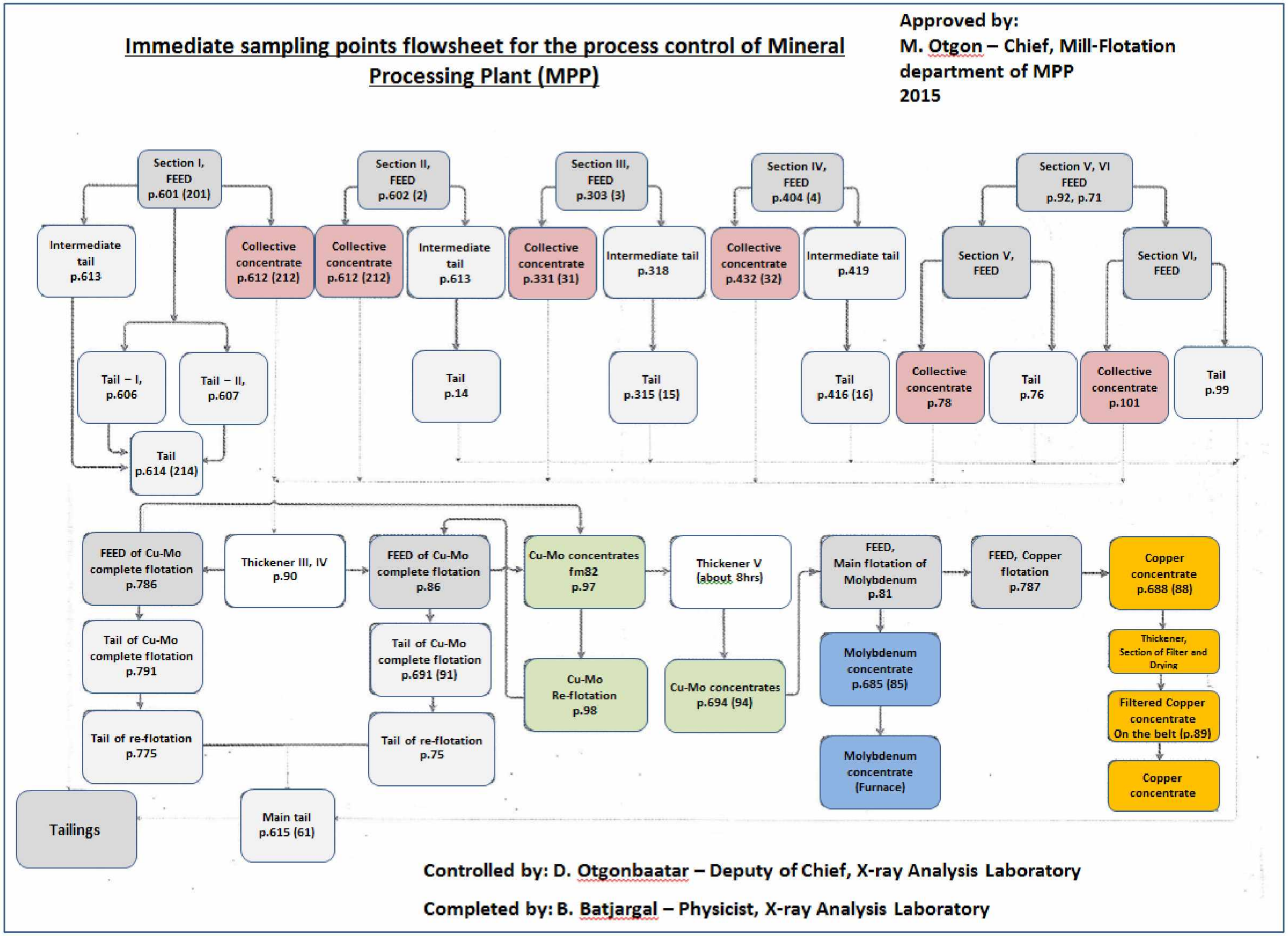

Figure 8. Direct sampling points flowsheet for the process control of Mineral Processing Plant

Table 4. A snapshot of the data record of flotation process by Sections I – IV (KKD – ball mill line)

Date / Shifts	to ball mills, tonne	to flotation, tonne	Cu, %	Cu, t	Mo, %	Mo, t
01/01/2015 08:00:00	21133.47	20557.21	0.50	101.95	0.015	3.098
01/01/2015 04:00:00	21056.38	20506.55	0.51	104.32	0.016	3.336
01/02/2015 12:00:00	21070.91	20467.97	0.53	107.94	0.015	3.106
01/02/2015 08:00:00	20503.63	19594.00	0.52	102.66	0.014	2.819
01/02/2015 04:00:00	18133.70	17661.96	0.52	92.05	0.017	2.966
01/03/2015 12:00:00	18627.93	18179.74	0.51	92.57	0.017	3.109
01/03/2015 08:00:00	18848.53	18319.42	0.54	99.22	0.015	2.835
01/03/2015 04:00:00	18782.71	18289.76	0.53	97.83	0.013	2.450
01/04/2015 12:00:00	18768.71	18209.81	0.53	95.74	0.013	2.290
01/04/2015 08:00:00	18769.33	18209.81	0.53	96.21	0.012	2.148
01/04/2015 04:00:00	18763.97	18227.61	0.51	92.67	0.013	2.303
01/05/2015 12:00:00	18788.74	18240.85	0.48	88.12	0.013	2.423
01/05/2015 08:00:00	18855.66	18322.77	0.50	92.17	0.014	2.535
01/05/2015 04:00:00	18841.51	18319.91	0.52	95.96	0.014	2.616
01/06/2015 12:00:00	18861.35	18310.22	0.54	98.84	0.014	2.642
01/06/2015 08:00:00	18739.72	18257.71	0.52	94.95	0.014	2.477
01/06/2015 04:00:00	18035.54	17509.47	0.51	90.10	0.012	2.127
01/07/2015 12:00:00	18645.60	18174.89	0.55	99.18	0.013	2.285
01/07/2015 08:00:00	18752.60	18223.98	0.58	105.55	0.015	2.706
01/07/2015 04:00:00	18696.09	18215.96	0.56	102.14	0.014	2.605
01/08/2015 12:00:00	18646.98	18109.15	0.53	95.82	0.013	2.328
01/08/2015 08:00:00	18784.23	18259.28	0.56	101.38	0.015	2.800
01/08/2015 04:00:00	18760.66	18256.93	0.55	101.08	0.016	2.929
01/09/2015 12:00:00	18689.02	18153.55	0.55	99.70	0.013	2.426
01/09/2015 08:00:00	18753.08	18289.76	0.56	102.08	0.014	2.612
01/09/2015 04:00:00	18617.59	18093.61	0.55	98.73	0.015	2.638
01/10/2015 12:00:00	20137.28	19883.06	0.52	103.78	0.014	2.746
01/10/2015 08:00:00	20856.48	20347.31	0.50	100.74	0.014	2.898
01/10/2015 04:00:00	21001.40	20429.17	0.47	96.14	0.012	2.432
01/11/2015 12:00:00	21027.58	20464.93	0.44	90.36	0.012	2.524
01/11/2015 08:00:00	21080.40	20521.11	0.48	99.32	0.013	2.634
01/11/2015 04:00:00	21098.98	20526.17	0.50	102.42	0.013	2.689
01/12/2015 12:00:00	21139.12	20568.69	0.51	104.75	0.014	2.956
01/12/2015 08:00:00	20715.61	19678.39	0.53	104.48	0.015	3.027
01/12/2015 04:00:00	16618.52	16071.93	0.49	78.91	0.014	2.182
01/13/2015 12:00:00	16512.28	16085.59	0.48	77.74	0.013	2.046
01/13/2015 08:00:00	16503.73	16029.25	0.48	76.55	0.013	2.132
01/13/2015 04:00:00	18127.29	17905.23	0.49	87.07	0.013	2.345
01/14/2015 12:00:00	18610.40	18121.54	0.48	86.62	0.015	2.642
01/14/2015 08:00:00	18758.05	18261.22	0.48	87.84	0.016	2.865
01/14/2015 04:00:00	19048.91	18779.22	0.50	93.77	0.016	2.952
01/15/2015 12:00:00	20857.04	20293.37	0.50	101.82	0.015	3.047
01/15/2015 08:00:00	20907.81	19815.08	0.50	98.47	0.013	2.593
01/15/2015 04:00:00	-	18043.94	0.52	94.38	0.014	2.581
01/16/2015 12:00:00	-	17790.77	0.52	92.70	0.013	2.369

2.2.3. Data record through KSI (SAG mill line)

Ore preparation and mill

The SAG mill line of MPP came into operation in December 1989, which corresponds to the extension of the mine capacity up to 20.0 million tonnes-per-year. The SAG mill line initially projected a capacity of 4.0 million tonnes-per-year, and in 2015 the capacity extended to 9.0 million tonnes-per-year.

The SAG mill line receives the –1000mm fraction of the ore material from OPM and crushes to –20mm for the flotation process.

The SAG mill line includes one jaw crusher (ЩДП-15*21, 1000/300mm), six silos for the stockpile of large crushed ore with a capacity of 10,000-15,000 tonnes each, three SAG mills (ММС-9.0*3.0 and ММС-9.75*4.88), three ball mills (МШЦ-5.5*6.5 and МШЦ-9.7*9.75) for the fine grinding and transporting conveyors, and pipes for pulp.

In the ore preparation section, data was obtained using the following for KSI:
- "**Received ore KSI**" by tonnage (crushed through jaw crushers)
- "**to Silos**" stockpile of large crushed ore by tonnage (after the jaw crusher on conveyor #71)
- "**to SAG mills**" ore material by tonnage (from silos on conveyors #72, 73, 74 and 75)

For example, the tonnage record of ore preparation is shown in Table 5 for the first half of January 2015.

The tonnage on conveyor #71, which is **"to silos"**, and conveyors #72, 73, 74 and 75, which are in the **"to SAG mills"** columns, were recorded on a tonnes-per-hour basis. Those conveyors tonnage data were obtained by multiplying by 8 hours for the shift.

Table 5. The data record of ore preparation by KSI

Date / Shifts	Received ore KSI	to silos (conveyor #71)	to SAG mills (conveyors #72, 73, 74, 75)
01/01/2015 08:00:00	1794	2452.10	3299.92
01/01/2015 04:00:00	0	0.00	3287.08
01/02/2015 12:00:00	0	0.00	2965.83
01/02/2015 08:00:00	7592	6989.22	2880.96
01/02/2015 04:00:00	0	1169.21	3100.64
01/03/2015 12:00:00	0	0.00	3135.40
01/03/2015 08:00:00	7840	7913.14	2975.97
01/03/2015 04:00:00	0	1069.67	3119.79
01/04/2015 12:00:00	0	0.00	2898.74
01/04/2015 08:00:00	8372	8056.77	3229.74
01/04/2015 04:00:00	0	1272.29	3153.99
01/05/2015 12:00:00	0	0.00	3105.39
01/05/2015 08:00:00	7483	7698.02	3044.82
01/05/2015 04:00:00	0	1034.88	407.38
01/06/2015 12:00:00	0	0.00	0.00
01/06/2015 08:00:00	0	0.00	0.00
01/06/2015 04:00:00	0	0.00	2286.16
01/07/2015 12:00:00	0	0.00	3079.95
01/07/2015 08:00:00	8907	8670.44	2949.84
01/07/2015 04:00:00	0	1295.37	3029.54
01/08/2015 12:00:00	0	0.00	3060.59
01/08/2015 08:00:00	7642	8168.50	3256.60
01/08/2015 04:00:00	115	1098.52	3282.93
01/09/2015 12:00:00	0	0.00	2960.91
01/09/2015 08:00:00	7949	8691.30	3203.81
01/09/2015 04:00:00	0	1239.26	4338.81
01/10/2015 12:00:00	0	0.92	5186.26
01/10/2015 08:00:00	7748	7719.96	3156.59
01/10/2015 04:00:00	0	1174.40	6102.43
01/11/2015 12:00:00	4328	3616.17	4937.99
01/11/2015 08:00:00	8208	9893.92	5673.19
01/11/2015 04:00:00	0	1265.41	5670.81
01/12/2015 12:00:00	8246	8475.22	5781.03
01/12/2015 08:00:00	8843	10180.28	5853.44
01/12/2015 04:00:00	0	1310.49	3454.04
01/13/2015 12:00:00	0	0.00	3923.22
01/13/2015 08:00:00	8742	8997.33	6128.91
01/13/2015 04:00:00	6423	7906.60	5336.88
01/14/2015 12:00:00	0	1398.56	5895.52
01/14/2015 08:00:00	8779	8970.40	5938.74
01/14/2015 04:00:00	0	1078.04	3421.19
01/15/2015 12:00:00	7804	8096.53	4367.34
01/15/2015 08:00:00	8033	7554.70	5752.20
01/15/2015 04:00:00	0	0.00	0.00
01/16/2015 12:00:00	7432	0.00	0.00

Flotation

The flotation process belongs to the Milling-Flotation Section (MFS) of MPP. The MFS receives the –74μm fraction of ore material by pulp directly from the SAG mill section, and conducts the flotation process through V and VI out of six sections. Sections V, VI relate to the KSI (SAG mill line).

The data record of feed by tonnage and copper (Cu), molybdenum (Mo) grades to the flotation sections V, VI were measured on the points p.71 and p.92 (Figure 8).

In the flotation process section, data was obtained on the following:

- "**to flotation"** by tonnage and Cu, Mo grade

  (After SAG mills, the feed to flotation on the points: Section V – p.71 and Section VI – p.92)

For example, the tonnage and grade record of the flotation process is shown in Table 6 for the first half of January 2015.

In the column "**to flotation**" the feed tonnage was summed together on the sampling points p.71 and p.92. The copper and molybdenum grades in the sections V, VI were calculated from sampling points p.71 and p.92.

Table 6. The data record of flotation process by sections V, VI (KSI – SAG mill line)

Date / Shifts	to Flotation (sections V, VI from SAG mills)	Cu %	Mo%
01/01/2015 08:00:00	3197.12	0.47	0.013
01/01/2015 04:00:00	3134.39	0.46	0.011
01/02/2015 12:00:00	2823.67	0.45	0.016
01/02/2015 08:00:00	2793.60	0.54	0.020
01/02/2015 04:00:00	2978.71	0.51	0.016
01/03/2015 12:00:00	2991.48	0.50	0.014
01/03/2015 08:00:00	2836.28	0.47	0.012
01/03/2015 04:00:00	2992.62	0.49	0.011
01/04/2015 12:00:00	2802.33	0.47	0.013
01/04/2015 08:00:00	2991.48	0.49	0.012
01/04/2015 04:00:00	3145.07	0.44	0.012
01/05/2015 12:00:00	2949.77	0.47	0.013
01/05/2015 08:00:00	2918.83	0.46	0.014
01/05/2015 04:00:00	-	-	-
01/06/2015 12:00:00	-	-	-
01/06/2015 08:00:00	-	-	-
01/06/2015 04:00:00	2586.02	0.22	0.007
01/07/2015 12:00:00	2927.46	0.17	0.005
01/07/2015 08:00:00	2818.82	0.15	0.005
01/07/2015 04:00:00	2912.03	0.50	0.013
01/08/2015 12:00:00	2963.49	0.47	0.013
01/08/2015 08:00:00	3099.15	0.50	0.014
01/08/2015 04:00:00	3093.05	0.52	0.017
01/09/2015 12:00:00	2899.33	0.53	0.016
01/09/2015 08:00:00	3057.68	0.57	0.021
01/09/2015 04:00:00	4525.83	0.61	0.019
01/10/2015 12:00:00	4630.78	0.57	0.023
01/10/2015 08:00:00	3330.53	0.51	0.016
01/10/2015 04:00:00	5845.22	0.57	0.015
01/11/2015 12:00:00	4535.15	0.54	0.011
01/11/2015 08:00:00	5709.48	0.51	0.013
01/11/2015 04:00:00	5352.46	0.46	0.013
01/12/2015 12:00:00	5642.48	0.45	0.015
01/12/2015 08:00:00	5697.78	0.46	0.012
01/12/2015 04:00:00	2956.56	0.24	0.006
01/13/2015 12:00:00	4139.37	0.09	0.002
01/13/2015 08:00:00	5811.27	0.06	0.002
01/13/2015 04:00:00	5204.05	0.07	0.002
01/14/2015 12:00:00	5659.95	0.50	0.014
01/14/2015 08:00:00	5717.18	0.46	0.013
01/14/2015 04:00:00	2826.57	0.11	0.003
01/15/2015 12:00:00	4674.43	0.48	0.012
01/15/2015 08:00:00	5692.88	0.49	0.012
01/15/2015 04:00:00	5949.01	0.49	0.014
01/16/2015 12:00:00	5449.46	0.47	0.012

2.3 Consolidation of Mine-Mill data

The metal content of mine data and mill data was computed from ore grades separately. Both data sets were also organized so they could be compared on a shift basis. For example, Table 7 shows consolidated mine and mill data for first half of January 2015. In Table 7, the two sets of yellow colored columns indicate loaded ore to KKD from the mine and the processed ore by ball mill line (KKD). Also the two sets of blue colored columns indicate loaded ore to KSI from the mine and the processed ore by SAG mill line (KSI).

Table 7. Consolidated Mine to Mill data for the first half of January 2015

	MINE										MILL																
	MINE to KKD					MINE to KSI					Processing ore by KKD									Processing ore by KSI							
Date / Shifts	KKD, th.t	Cu, %	Cu, tonne	Mo, %	Mo, tonne	KSI, th.t	Cu, %	Cu, tonne	Mo, %	Mo, tonne	Received ore KKD ,tonne	To 1st stockpile ,tonne	To 3rd stockpile , tonne	to Ball mills, tonne	to Flotation , tonne	Cu, %	Cu, t	Mo, %	Mo, t	Received ore KSI, tonne	to Silos, tonne	to SAGs, tonne	Flotation , tonne	Cu, %	Cu, tonne	Mo, %	Mo, tonne
01/01/2015 08:00:00	21.96	0.501967	110.232	0.016514	3.626	1.8	0.518	9.324	0.0156	0.2808	21293	21813.00	21939.00	21133.47	20557.21	0.50	101.95	0.015	3.098	1794	2452.10	3299.92	3197.12	0.47	14.96	0.013	0.416
01/01/2015 04:00:00	20.04	0.508802	101.964	0.014341	2.874	0	0	0	0	0	19902	20923.17	19620.00	21056.38	20506.55	0.51	104.32	0.016	3.336	0	0.00	3287.08	3134.39	0.46	14.29	0.011	0.345
01/02/2015 12:00:00	22.2	0.504324	111.96	0.014838	3.294	0	0	0	0	0	21821	22114.38	19599.00	21070.91	20467.97	0.53	107.94	0.015	3.106	0	0.00	2965.83	2823.67	0.45	12.82	0.016	0.452
01/02/2015 08:00:00	21	0.512286	107.58	0.01848	3.881	7.8	0.507231	39.564	0.013554	1.0572	20773	21871.50	20440.00	20503.63	19594.00	0.52	102.66	0.014	2.819	7592	6989.22	2880.96	2793.60	0.54	15.20	0.020	0.559
01/02/2015 04:00:00	10.32	0.500465	51.648	0.010314	1.064	0	0	0	0	0	10243	10216.53	10557.00	18133.70	17661.96	0.52	92.05	0.017	2.966	0	1169.21	3100.64	2978.71	0.51	15.19	0.016	0.477
01/03/2015 12:00:00	21.48	0.509274	109.392	0.013855	2.976	0	0	0	0	0	21378	21828.22	23542.00	18627.93	18179.74	0.51	92.57	0.017	3.109	0	0.00	3135.40	2991.48	0.50	14.84	0.014	0.419
01/03/2015 08:00:00	23.16	0.511917	118.56	0.013896	3.218	7.92	0.509697	40.368	0.012909	1.0224	22405	23355.14	21927.00	18848.53	18319.42	0.54	99.22	0.015	2.835	7840	7913.14	2975.97	2836.28	0.47	13.19	0.012	0.340
01/03/2015 04:00:00	20.64	0.496512	102.48	0.011977	2.472	0	0	0	0	0	20590	21064.68	20534.00	18782.71	18289.76	0.53	97.83	0.013	2.450	0	1069.67	3119.79	2992.62	0.49	14.72	0.011	0.329
01/04/2015 12:00:00	19.2	0.502688	96.516	0.025294	4.856	0	0	0	0	0	19284	20297.50	18470.00	18768.71	18209.81	0.53	95.74	0.013	2.290	0	0.00	2898.74	2802.33	0.47	13.23	0.013	0.364
01/04/2015 08:00:00	20.16	0.515298	103.884	0.024589	4.957	8.5	0.508612	43.232	0.012	1.02	20088	19853.36	21310.00	18769.33	18209.81	0.53	96.21	0.012	2.148	8372	8056.77	3229.74	2991.48	0.49	14.66	0.012	0.359
01/04/2015 04:00:00	20.52	0.512807	105.228	0.014901	3.058	0	0	0	0	0	20675	21145.06	19646.00	18763.97	18227.61	0.51	92.67	0.013	2.303	0	1272.29	3153.99	3145.07	0.44	13.90	0.012	0.377
01/05/2015 12:00:00	11.4	0.508421	57.96	0.032695	3.727	0	0	0	0	0	11176	12076.04	13804.00	18788.74	18240.85	0.48	88.12	0.013	2.423	0	0.00	3105.39	2949.77	0.47	13.92	0.013	0.383
01/05/2015 08:00:00	22.32	0.496505	110.82	0.013059	2.915	8.16	0.501324	40.908	0.016897	1.3788	21542	22016.95	22057.00	18855.66	18322.77	0.50	92.17	0.014	2.535	7483	7698.02	3044.82	2918.83	0.46	13.48	0.014	0.409
01/05/2015 04:00:00	19.44	0.500309	97.26	0.032247	6.269	0	0	0	0	0	19044	19673.99	20460.00	18841.51	18319.91	0.52	95.96	0.014	2.616	0	1034.88	407.38	0.00	0.00	0.00	0.000	0.000
01/06/2015 12:00:00	20.88	0.502471	104.916	0.015402	3.216	0	0	0	0	0	20715	21143.86	17752.00	18861.35	18310.22	0.54	98.84	0.014	2.642	0	0.00	0.00	0.00	0.00	0.00	0.000	0.000
01/06/2015 08:00:00	19.56	0.505521	98.88	0.024706	4.832	0	0	0	0	0	20246	20939.07	21565.00	18739.72	18257.71	0.52	94.95	0.014	2.477	0	0.00	0.00	0.00	0.00	0.00	0.000	0.000
01/06/2015 04:00:00	4.56	0.5	22.8	0.015402	0.702	0	0	0	0	0	4562	3968.30	5325.00	18035.54	17509.47	0.51	90.10	0.012	2.127	0	0.00	2286.16	2586.02	0.22	5.82	0.007	0.181
01/07/2015 12:00:00	19.68	0.497805	97.968	0.01775	3.493	0	0	0	0	0	19828	20790.52	23365.00	18645.60	18174.89	0.55	99.18	0.013	2.285	0	0.00	3079.95	2927.46	0.17	4.88	0.005	0.148
01/07/2015 08:00:00	20.4	0.502294	102.468	0.029559	6.030	9.24	0.493766	45.624	0.032714	3.0228	20463	21230.55	20211.00	18752.60	18223.98	0.58	105.55	0.015	2.706	8907	8670.44	2949.84	2818.82	0.15	4.29	0.005	0.139
01/07/2015 04:00:00	21.24	0.513277	109.02	0.028492	6.052	0	0	0	0	0	20852	21079.98	21465.00	18696.09	18215.96	0.56	102.14	0.014	2.605	0	1295.37	3029.54	2912.03	0.50	14.59	0.013	0.379
01/08/2015 12:00:00	17.64	0.501293	88.428	0.025646	4.524	0	0	0	0	0	17228	19624.57	15163.00	18646.98	18109.15	0.53	95.82	0.013	2.328	0	0.00	3060.59	2963.49	0.47	14.05	0.013	0.385
01/08/2015 08:00:00	20.76	0.505434	104.928	0.021098	4.380	8.04	0.514179	41.34	0.011	0.8844	20176	20319.30	20067.00	18784.23	18259.28	0.56	101.38	0.015	2.800	7642	8168.50	3256.60	3099.15	0.50	15.56	0.014	0.434
01/08/2015 04:00:00	20.52	0.506316	103.896	0.024754	5.080	0	0	0	0	0	20007	20150.39	18877.00	18760.66	18256.93	0.55	101.08	0.016	2.929	115	1098.52	3282.93	3093.05	0.52	15.96	0.017	0.526
01/09/2015 12:00:00	14.28	0.504538	72.048	0.020067	2.866	0	0	0	0	0	14029	15251.91	16071.00	18689.02	18153.55	0.55	99.70	0.013	2.426	0	0.00	2960.91	2899.33	0.53	15.48	0.016	0.475
01/09/2015 08:00:00	19.68	0.519695	102.276	0.016183	3.185	8.16	0.518088	42.276	0.011662	0.9516	19693	20555.09	21872.00	18753.08	18289.76	0.56	102.08	0.014	2.612	7949	8691.30	3203.81	3057.68	0.57	17.31	0.021	0.642
01/09/2015 04:00:00	9.72	0.497901	48.396	0.016728	1.626	0	0	0	0	0	9733	12961.90	9602.00	18617.59	18093.61	0.55	98.73	0.015	2.638	0	1239.26	4338.81	4525.83	0.61	27.47	0.019	0.860
01/10/2015 12:00:00	17.76	0.513311	91.164	0.020358	3.616	0	0	0	0	0	19058	16516.43	20827.00	20137.28	19883.06	0.52	103.78	0.014	2.746	0	0.92	5186.26	4630.78	0.57	26.63	0.023	1.065
01/10/2015 08:00:00	22.2	0.517676	114.924	0.015232	3.382	8.16	0.511618	41.748	0.016985	1.386	21638	21609.30	22921.00	20856.48	20347.31	0.50	100.74	0.014	2.898	7748	7719.96	3156.59	3330.53	0.51	17.02	0.016	0.546
01/10/2015 04:00:00	21.12	0.466875	98.604	0.013943	2.945	0	0	0	0	0	20826	21605.04	23048.00	21001.40	20429.17	0.47	96.14	0.012	2.432	0	1174.40	6102.43	5845.22	0.57	33.32	0.015	0.877
01/11/2015 12:00:00	21.48	0.516201	110.88	0.013039	2.801	4.44	0.501622	22.272	0.012703	0.564	21611	22223.89	20625.00	21027.58	20464.93	0.44	90.36	0.012	2.524	4328	3616.17	4937.99	4535.15	0.54	24.67	0.011	0.499
01/11/2015 08:00:00	23.52	0.497194	116.94	0.013643	3.209	8.64	0.49	42.336	0.013	1.1232	22416	22916.58	21485.00	21080.40	20521.11	0.48	99.32	0.013	2.634	8208	9893.92	5673.19	5709.48	0.51	29.00	0.013	0.742
01/11/2015 04:00:00	21	0.5104	107.184	0.01552	3.259	0	0	0	0	0	20549	21890.99	20949.00	21098.98	20526.17	0.50	102.42	0.013	2.689	0	1265.41	5670.81	5352.46	0.46	24.46	0.013	0.701
01/12/2015 12:00:00	21.84	0.501923	109.62	0.01461	3.191	8.64	0.50125	43.308	0.013875	1.1988	21589	22388.40	21165.00	21139.12	20568.69	0.51	104.75	0.014	2.956	8246	8475.22	5781.03	5642.48	0.45	25.62	0.015	0.869
01/12/2015 08:00:00	23.16	0.508446	117.756	0.013497	3.126	9.24	0.507922	46.932	0.015701	1.4508	22491	23122.21	21951.00	20715.61	19678.39	0.53	104.48	0.015	3.027	8843	10180.28	5853.44	5697.78	0.46	26.32	0.012	0.684
01/12/2015 04:00:00	19.44	0.52037	101.16	0.011605	2.256	0	0	0	0	0	19330	20509.12	17411.00	16618.52	16071.93	0.49	78.91	0.014	2.182	0	1310.49	3454.04	2956.56	0.24	7.15	0.006	0.169
01/13/2015 12:00:00	13.44	0.503571	67.68	0.01475	1.982	0	0	0	0	0	13405	13667.28	12760.00	16512.28	16085.59	0.48	77.74	0.013	2.046	0	0.00	3923.22	4139.37	0.09	3.81	0.002	0.091
01/13/2015 08:00:00	19.2	0.507125	97.368	0.013313	2.556	9	0.509733	45.876	0.01552	1.3968	17639	18693.81	20326.00	16503.73	16029.25	0.48	76.55	0.013	2.132	8742	8997.33	6128.91	5811.27	0.06	3.22	0.002	0.093
01/13/2015 04:00:00	8.52	0.49338	42.036	0.013155	1.121	6.36	0.507358	32.268	0.012736	0.81	8474	7959.13	8311.00	18127.29	17905.23	0.49	87.07	0.013	2.345	6423	7906.60	5336.88	5204.05	0.07	3.64	0.002	0.096
01/14/2015 12:00:00	20.16	0.509286	102.672	0.013935	2.809	0	0	0	0	0	19652	20867.42	21852.00	18610.40	18121.54	0.48	86.62	0.015	2.642	0	1398.56	5895.52	5659.95	0.50	28.24	0.014	0.792
01/14/2015 08:00:00	20.52	0.504327	103.488	0.012988	2.665	9	0.523067	47.076	0.015627	1.4064	20213	20689.18	21306.00	18758.05	18261.22	0.48	87.84	0.016	2.865	8779	8970.40	5938.74	5717.18	0.46	26.41	0.013	0.749
01/14/2015 04:00:00	20.64	0.50093	103.392	0.01214	2.506	0	0	0	0	0	20791	20962.64	21238.00	19048.91	18779.22	0.50	93.77	0.016	2.952	0	1078.04	3421.19	2826.57	0.11	2.98	0.003	0.079
01/15/2015 12:00:00	17.52	0.507945	88.992	0.01389	2.434	8.16	0.498235	40.656	0.011471	0.936	17953	19459.60	19062.00	20857.04	20293.37	0.50	101.82	0.015	3.047	7804	8096.53	4367.34	4674.43	0.48	22.25	0.012	0.561
01/15/2015 08:00:00	21.24	0.534859	113.604	0.015463	3.284	8.28	0.522174	43.236	0.01542	1.2768	20461	15267.34	20807.00	20907.81	19815.08	0.50	98.47	0.013	2.593	8033	7554.70	5752.20	5692.88	0.49	27.78	0.012	0.683
01/15/2015 04:00:00	17.64	0.526463	92.868	0.012694	2.239	0	0	0	0	0	16907	0.00	18711.00	0.00	18043.94	0.52	94.38	0.014	2.581	0	0.00	0.00	5949.01	0.49	28.97	0.014	0.833
01/16/2015 12:00:00	16.92	0.50922	86.16	0.014589	2.468	7.08	0.502373	35.568	0.015136	1.0716	18179	0.00	19039.00	0.00	17790.77	0.52	92.70	0.013	2.369	7432	0.00	0.00	5449.46	0.47	25.88	0.012	0.654

2.4 Balance sheet in the period 2011-2015

The annual closure balance sheet by key performance of EMC was obtained for 2011-2015 for the mine and the mill (Tables 8 and 9), respectively. These tables are produced separately by the two departments, OPM and MPP. This information was used to verify the raw, granular data that was obtained from these departments.

Table 8. Actual output of OPM in 2011-2015 (obtained from OPM department)

No	Name	Unit	Years				
			2011	2012	2013	2014	2015
1	to MPP	th.t	26100	26032	26055	26123	28000
2	Metal Cu in the ore	t	141074	140914	137898	137501.9	144538.5
3	Metal Mo in the ore	t	4338.23	4227.16	4034.63	4904.44	5687.79
4	Ore grade: - Cu - Mo	 % %	 0.541 0.017	 0.541 0.016	 0.529 0.015	 0.526 0.019	 0.516 0.020

Table 9. Actual output of MPP in 2011-2015 (obtained from MPP department)

No	Name	Unit	Years				
			2011	2012	2013	2014	2015
1	Processed ore	th.t	26100	26030	26045	26126	28000
2	Metal Cu in copper concentrate	t	121601	121679	119155	119026	127510.3
3	Metal Mo in molybdenum concentrate	t	1956.6	1903.617	1818.53	1999.587	2557.138
4	Ore grade: - Cu - Mo	 % %	 0.540 0.0166	 0.542 0.0163	 0.53 0.0155	 0.526 0.0188	 0.516 0.0203
5	Copper contents in Cu concentrate	%	23.67	23.5	23.23	23.03	23.35
6	Molybdenum contents in Mo concentrate	%	49.19	48.39	48.73	49.32	49.11
7	Recovery Cu	%	86.35	86.3	86.3	86.55	88.22
8	Recovery Mo	%	45.10	45.0	45.07	40.0	44.94

2.5 Data analysis

Data record gaps:

The MPP shuts down one day (three shifts) for the annual planned maintenance work, usually during the first ten days of July. In this period no data are recorded for both the mine and mills. Additionally, mining and milling data are occasionally missing for unknown reasons. These data gaps can create problems for modeling, and therefore have to be addressed before applying techniques such as the artificial neural network (ANN). The following approaches were taken to address data gaps:

1. Confirm that the gap is incorrect. When data is absent for a legitimate reason like shut downs, the gap is accepted.
2. Remove the whole row from the records when either mine or mill show no data.
3. Fill those gaps using some methods of statistics.
4. In some cases, gaps are used to create subsets in the dataset, i.e. data before the gap is modeled differently from the data after the gap.

Mass balance tonnage:

The data show that the tonnage and copper metal are more on the mill side than on the mine side. This may be caused by a combination of two factors: estimate of volume mined, and specific gravity of *in situ* rock. OPM surveys the mined area and determines the volume that was mined. EMC uses a density of 2.55 t/m^3 for *in situ* rock. EMC determined this density about 20 years ago. The tonnage in the mill, on the other hand, is measured using belt scales just before flotation stage. It is possible that the actual *in situ* density now is 2.65 t/m^3. To examine the effect of density, Table 10 compares tonnage and metal copper as computed using both densities, 2.55 t/$m^3$and 2.65 t/m^3.

Table 10. Comparison of mine and mill mass balance assuming two different specific gravities: 2.55 and 2.65

Years	TOTAL	Processed ore (Mill data)	Loaded ore from the mine s.g. = 2.55 (Mine data)	Loaded ore from the mine s.g. = 2.65
2011* July gap	Ore	24 805 368	24 279 900	25 251 096
	Copper	116 559	132 374	137 669
2012	Ore	25 991 936	24 568 680	25 505 623
	Copper	125 645	132 597	137 654
2013	Ore	26 028 191	25 061 010	26 063 450
	Copper	139 119	133 821	139 174
2014	Ore	26 062 380	25 462 970	26 396 396
	Copper	135 595	130 868	135 669
2015** January	Ore	2 092 421	2 056 012	2 138 252
	Copper	10 433	10 428	10 845

*-Mine data had a gap all during July; this row is ignored in both the mine and mill data record in July.

**-Mine data was only in January, so mine and mill data records were compared only in January.

From Table 10, for years 2012-2014 the originally recorded mine data with density of 2.55t/m^3 is less than the processed ore. If ore material tonnage is calculated with density of 2.65t/m^3, processed and mined ore tonnage almost match each other. This may be evidence that OPM is using the wrong density.

3. Data Mining

3.1 Aggregation and Period of mine and mill dataset

Aggregate Width (AW):

One would expect silos to retain material for several shifts or even days. Therefore, one could aggregate production data for several shifts or days before looking for a relationship between mine data and mill data. The raw data is on a shift basis. Aggregate width is the number of shifts by which the data are aggregated. Many AW are examined in this analysis. The aggregation of data is considered the average value of the number of shifts considered.

The total number of rows of data sets are 1090 for both 2013 and 2014. The total rows are aggregated by three to twelve rows of data (one row means one shift). The reason is the valuable effective capacity of total first and third stockpiles of ore, which feed the flotation section for three shifts (one day), as well making today's ore from the open pit mine possible to go through the processing plant in a maximum of fifteen shifts (five days).

For example, the AW, Days and Hours are tabulated in Table 11. The aggregation width is shown in Figure 9.

Table 11. Correspondence of AW, days and hours

AW (shifts)	3	4	5	6	7	8	9	10	11	12	13	14	15
Days	1	$1\frac{1}{3}$	$1\frac{2}{3}$	2	$2\frac{1}{3}$	$2\frac{2}{3}$	3	$3\frac{1}{3}$	$3\frac{2}{3}$	4	$4\frac{1}{3}$	$4\frac{2}{3}$	5
Hrs.	24	32	40	48	56	64	72	80	88	96	104	112	120

Aggregate width = 3

Date / Shifts	Cu, tonne Mine KKD	Cu, tonne Mill KKD
01/01/2014 08:00:00	117.1507843	112.0402175
01/01/2014 04:00:00	104.9607843	115.9857519
01/02/2014 12:00:00	121.9935294	114.5598675

.
.
.

Aggregate width = 6

Date / Shifts	Cu, tonne Mine KKD	Cu, tonne Mill KKD
01/01/2014 08:00:00	117.1507843	112.0402175
01/01/2014 04:00:00	104.9607843	115.9857519
01/02/2014 12:00:00	121.9935294	114.5598675
01/02/2014 08:00:00	125.3709804	113.5924476
01/02/2014 04:00:00	112.6198039	104.4474607
01/03/2014 12:00:00	102.1756863	114.6620734

.
.
.

Aggregate width = 15

Date / Shifts	Cu, tonne Mine KKD	Cu, tonne Mill KKD
01/01/2014 08:00:00	117.1507843	112.0402175
01/01/2014 04:00:00	104.9607843	115.9857519
01/02/2014 12:00:00	121.9935294	114.5598675
01/02/2014 08:00:00	125.3709804	113.5924476
01/02/2014 04:00:00	112.6198039	104.4474607
01/03/2014 12:00:00	102.1756863	114.6620734
01/03/2014 08:00:00	100.8247059	117.0932572
01/03/2014 04:00:00	72.49568627	112.3397072
01/04/2014 12:00:00	85.21568627	102.2404556
01/04/2014 08:00:00	118.855098	108.0470677
01/04/2014 04:00:00	113.6694118	117.5977608
01/05/2014 12:00:00	115.4464706	112.3993048
01/05/2014 08:00:00	113.1082353	112.7312898
01/05/2014 04:00:00	110.4582353	99.26053242
01/06/2014 12:00:00	113.4719608	110.9051348

Figure 9. Aggregation width

Period:

After the data is aggregated, each row is called a “period”. One period will represent varying lengths of time depending on AW. If AW is 3, one period represents 3 shifts (or one day). For AW=6, one period represents six shifts or two days. Periods are non-overlapping.

3.2 Number of Periods, Period Length and Block Count

Correlation is being determined only for a maximum period of about a month as periods longer than that are not useful for analyzing mine-mill grade differences.

Number of Periods (N):

This is the number of data points used to compute the correlation between mine data and mill data. A minimum value of 5 has been used for N.

Period Length (PL):

This is the same as N, but expressed in days. Thus, N of 5 for AW3, would mean PL5. An N of 5 for AW6 would result in PL10. The period length is expressed using the following simple formula:

$$PL = \frac{AW}{3} * N; (integer\ value) \tag{1}$$

where 3 is the number of shifts in one day. The PL of the dataset is shown in Table 12.

Table 12. The Period Length (PL) in days

Number of periods (N)	Aggregate Width (AW)												
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
5	***5***	7	8	***10***	12	13	15	17	18	20	22	23	25
6	6	8	10	12	14	16	18	20	22	24	26	28	30
7	7	9	12	14	16	19	21	23	26	28	30		
8	8	11	13	16	19	21	24	27	29				
9	9	12	15	18	21	24	27	30					
10	10	13	17	20	23	27	30						

Block Count:

A block represents the amount of data used for correlation. For example, for PL=10, ten days worth of data are used to compute correlation and, therefore, the block size is 10. There will be approximately 36 non-overlapping blocks of data for a year. If the PL was 20, the annual data will be reduced to approximately 18 non-overlapping blocks of data. When AW is increased and the N is kept constant, the number of blocks in the dataset is reduced.

The block count is expressed using the following simple formula:

$$BC = \frac{totalRows\ (number\ of\ shifts)}{AW*N};(integer\ value) \tag{2}$$

Both of the datasets for 2013 and 2014 included 1090 total rows (shifts). The block count of the dataset is shown in Table 13.

Table 13. The Block counts in the one year dataset

Number of periods (N)	Aggregate Width (AW)												
	3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
5	73	55	44	***36***	31	27	24	22	20	***18***	**17**	**16**	**15**
6	61	45	36	30	26	23	20	18	17	15	14	13	12
7	52	39	31	26	22	19	17	16	14	13	12		
8	45	34	27	23	19	17	15	14	12				
9	40	30	24	20	17	15	13	12					
10	36	27	22	18	16	14	12						

Comparison of high correlation:

Percentage of blocks with correlation greater than 0.8 (PB0.8): Correlation is computed for each block of data. The percentage of blocks with correlation greater than 0.8 is then noted for various combinations of AW and N.

$$PB^{0.8} = \frac{PC^{0.8}}{BC}; \% \qquad (3)$$

In each block for which correlation was calculated, the counted peaks are more than r>0.8. The high correlation peak counts divided by block counts, an defined as the percentage of blocks with correlation greater than 0.8 (or $PB^{0.8}$). For example, in Table 14 aggregation width is AW3 from the 2014 dataset.

Table 14. Percentage of blocks with correlation greater than 0.8

Number of Periods, (N)	5	6	7	8	9	10
Period Length, (PL in days)	5	6	7	8	9	10
Peak Count, ($PC^{0.8}$)	17	12	7	4	2	2
Block Count, (BC)	73	61	52	45	40	36
Percentage, ($PB^{0.8}$)	**0.23**	**0.2**	**0.13**	**0.09**	**0.05**	**0.06**

3.3. The Delay Time of the Ore flow

Lag:

When correlation is computed between variables Y (mill copper) and X (mine copper), both variables typically represent the same time period. For example, Y and X may both represent the seven day period starting January 01, 2014. To examine the role of silos in material flow, correlation may also be computed showing slightly different time periods. For example, Y could represent the time period January 01-07, whereas X could represent January 02-08. In this case, lag is 3 shifts (1 day). The assumption in this case is that the mine material takes about one day to show up at the mill sensors. Lag is the time difference in start times for blocks of data being used for correlation. It is measured in periods.

The time delay causes lag by 0 to 10 shifts ($3\frac{1}{3}$ days). Lag 0 means that mined and milled productions are aligned in one row (in the same shift). Lag 10 means that mined ore will be processed ten shifts later on the flotation section (ten rows later). Table 15 contains an example of time delay from lag 0 to lag 10, for a period of 7 days (from 01/01/2014 to 01/07/2014).

Table 15. The time delay (Lag) by shifts in January 2014

	Y variable	X variable					
Date / Shifts	Mill CU, t	Mine CU, t					
		Lag 0	Lag 1	Lag 2	Lag 3	Lag . . .	Lag 10
01/01/2014 08:00:00	112.04	117.15					
01/01/2014 04:00:00	115.99	104.96	117.15				
01/02/2014 12:00:00	114.56	121.99	104.96	117.15			
01/02/2014 08:00:00	113.59	125.37	121.99	104.96	117.15		
01/02/2014 04:00:00	104.45	112.62	125.37	121.99	104.96		
01/03/2014 12:00:00	114.66	102.18	112.62	125.37	121.99		
01/03/2014 08:00:00	117.09	100.82	102.18	112.62	125.37		
01/03/2014 04:00:00	112.34	72.50	100.82	102.18	112.62		
01/04/2014 12:00:00	102.24	85.22	72.50	100.82	102.18		
01/04/2014 08:00:00	108.05	118.86	85.22	72.50	100.82		
01/04/2014 04:00:00	117.60	113.66	118.86	85.22	72.50		117.15
01/05/2014 12:00:00	112.40	115.44	113.66	118.86	85.22		104.96
01/05/2014 08:00:00	112.73	113.12	115.44	113.66	118.86		121.99
01/05/2014 04:00:00	99.26	110.45	113.12	115.44	113.66		125.37
01/06/2014 12:00:00	110.91	113.47	110.45	113.12	115.44		112.62
01/06/2014 08:00:00	92.15	115.26	113.47	110.45	113.12		102.18
01/06/2014 04:00:00	84.34	100.63	115.26	113.47	110.45		100.82
01/07/2014 12:00:00	84.79	109.11	100.63	115.26	113.47		72.50
01/07/2014 08:00:00	84.90	113.59	109.11	100.63	115.26		85.22
01/07/2014 04:00:00	86.21	53.69	113.59	109.11	100.63		118.86

3.4. Results and Analysis

3.4.1. Examinations of various AW correlations for 2013 and 2014

Limitation:

Correlation is determined only for a maximum period of about a month, as periods longer than that are not useful for analyzing mine-mill grade differences. In this case 12 blocks were checked during one year. A total of 24 blocks were examined in 2013 and 2014.

The total aggregation width from AW1 to AW15 considers the mine to mill ore flows with a maximum of a 5 day period.

Comparison of percentages with high AW correlations:

The percentages were calculated using formula (3). The examinations also were compared based on percentage of blocks with high correlation, which is greater than 0.8 (or $PB^{0.8}$).

The results of the 2013 and 2014 mine and mill dataset are summarized in Tables 16 and 17. Also high correlation peaks for each year with dates for various AWs on N5 are tabulated in the Appendix. The dates of high correlation are somewhat different for different AW.

Percentages of high correlation decrease as the period increases on the combinations of each AW. As aggregation width increases, the percentages of high correlation also increases (see Figures 10 and 11). The peaks in the plots are periodic ("waves"). This is not surprising as aggregations are repetitive – an aggregation width of six should have the same nature as an aggregate width of three. In this project, the first peak (or wave) will be examined because the next waves are a repeat of the previous results.

In 2013 (Figure 10), the first wave is observed at AW7 for period lengths 5 and 6. In 2014 (Figure 11), the first wave is observed at AW8 for period lengths 5, 6 and 7. Longer period lengths seem to have a lower correlation. For AW7, period length of 5 implies a period of 35 shifts (~12 days), while a period length of 6 implies 42 shifts (14 days). For AW8, period lengths of 5, 6 and 7 imply periods of 40, 48 and 56 shifts (~ 13, 16 and 19 days), respectively. In other words, the highest correlations occur for AW of 7 or 8. The high correlations are only observed at short periods (about 2 to 3 weeks). In conclusion, the flow of ore from mine to mill is complete in 2 to 3 days, not by shift to shift.

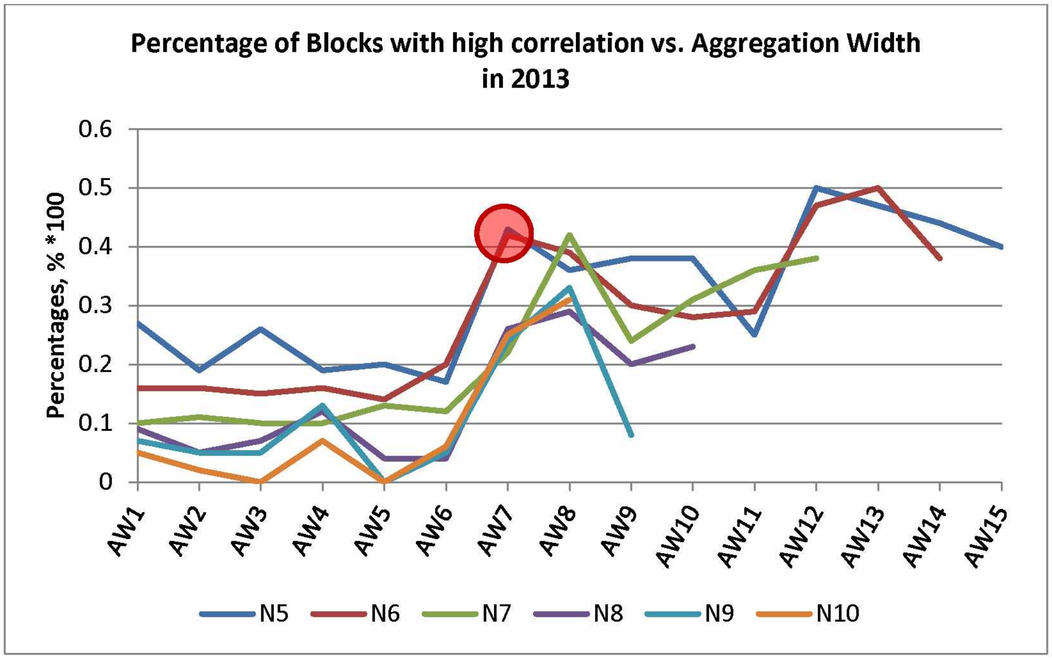

Figure 10. High correlation periods in 2013 for various AW, showing the first wave (as a red dot)

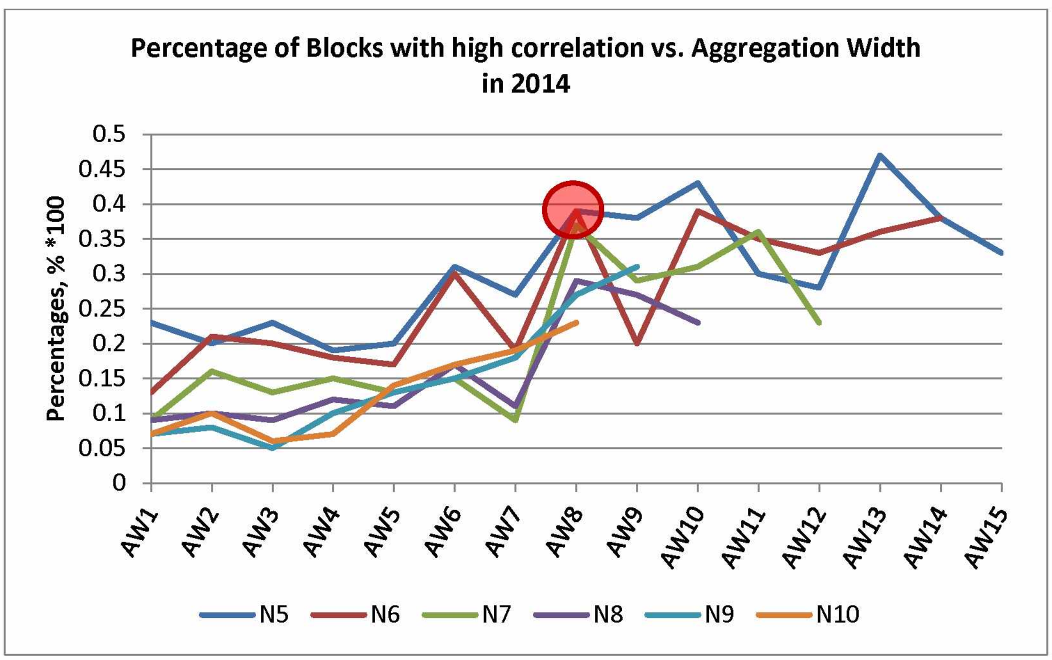

Figure 11. High correlation periods in 2014 for various AW, showing the first wave (as a red dot)

Table 16. Result of correlation analysis for 2013. Each cell (one is shaded in yellow) is split into four quadrants: period length (PL), peak count (PC), block count (BC) and "% above 0.8" (%). The first "wave" is highlighted in red.

	N	
AW	PL	PC
	BC	%

Aggregate Width (AW)	Number of periods (N): 5		6		7		8		9		10	
1	2	49	2	29	2	18	3	11	3	8	3	6
	182	0.27	182	0.16	182	0.1	121	0.09	121	0.07	121	0.05
2	3	23	4	15	5	8	5	4	6	3	7	1
	121	0.19	91	0.16	73	0.11	73	0.05	61	0.05	52	0.02
3	5	19	6	9	7	5	8	3	9	2	10	0
	73	0.26	61	0.15	52	0.1	45	0.07	40	0.05	36	0
4	7	10	8	7	9	4	11	4	12	4	13	2
	55	0.19	45	0.16	39	0.1	34	0.12	30	0.13	27	0.07
5	8	9	10	5	12	4	13	1	15	0	17	0
	44	0.2	36	0.14	31	0.13	27	0.04	24	0	22	0
6	10	6	12	6	14	3	16	1	18	1	20	1
	36	0.17	30	0.2	26	0.12	23	0.04	20	0.05	18	0.06
7	12	13	14	11	16	5	19	5	21	4	23	4
	31	0.43	26	0.42	22	0.22	19	0.26	17	0.24	16	0.25
8	13	10	16	9	19	8	21	5	24	5	27	4
	27	0.36	23	0.39	19	0.42	17	0.29	15	0.33	14	0.31
9	15	9	18	6	21	4	24	3	27	1		
	24	0.38	20	0.3	17	0.24	15	0.2	13	0.08		
10	17	8	20	5	23	5	27	3				
	22	0.38	18	0.28	16	0.31	14	0.23				
11	18	5	22	5	26	5						
	20	0.25	17	0.29	14	0.36						
12	20	9	24	7	28	5						
	18	0.5	15	0.47	13	0.38						
13	22	8	26	7								
	17	0.47	14	0.5								
14	23	7	28	5								
	16	0.44	13	0.38								
15	25	6										
	15	0.4										

Table 17. Result of correlation analysis for 2014. The format of the table is the same as Table 16. The first "wave" is highlighted in red.

	N	
AW	PL	PC
	BC	%

Aggregate Width (AW)	Number of periods (N) 5		6		7		8		9		10	
1	2	42	2	24	2	17	3	11	3	9	3	8
	182	0.23	182	0.13	182	0.09	121	0.09	121	0.07	121	0.07
2	3	24	4	19	5	12	5	7	6	5	7	5
	121	0.2	91	0.21	73	0.16	73	0.1	61	0.08	52	0.1
3	5	17	6	12	7	7	8	4	9	2	10	2
	73	0.23	61	0.2	52	0.13	45	0.09	40	0.05	36	0.06
4	7	10	8	8	9	6	11	4	12	3	13	2
	55	0.19	45	0.18	39	0.15	34	0.12	30	0.1	27	0.07
5	8	9	10	6	12	4	13	3	15	3	17	3
	44	0.2	36	0.17	31	0.13	27	0.11	24	0.13	22	0.14
6	10	11	12	9	14	4	16	4	18	3	20	3
	36	0.31	30	0.3	26	0.15	23	0.17	20	0.15	18	0.17
7	12	8	14	5	16	2	19	2	21	3	23	3
	31	0.27	26	0.19	22	0.09	19	0.11	17	0.18	16	0.19
8	13	11	16	9	19	7	21	5	24	4	27	3
	27	0.39	23	0.39	19	0.37	17	0.29	15	0.27	14	0.23
9	15	9	18	4	21	5	24	4	27	4		
	24	0.38	20	0.2	17	0.29	15	0.27	13	0.31		
10	17	9	20	7	23	5	27	3				
	22	0.43	18	0.39	16	0.31	14	0.23				
11	18	6	22	6	26	5						
	20	0.3	17	0.35	14	0.36						
12	20	5	24	5	28	3						
	18	0.28	15	0.33	13	0.23						
13	22	8	26	5								
	17	0.47	14	0.36								
14	23	6	28	5								
	16	0.38	13	0.38								
15	25	5										
	15	0.33										

3.4.2. Time delay (Lag) examination

The examination of time delay consisted of combinations of aggregation width AW3 to AW10 and numbers of periods 5 to 10. Note that as before, each period length represents a varying length of time depending on AW. Therefore, each plot in Figures 12 and 13 represents a different length of time. In Figure 12, the time lengths show trends for 5 days to 10 days, while Figure 13 shows time lengths of 8 days to 17 days. Note also that each lag represents different lengths of time depending on AW. For AW=3, lag1 represents a time difference of 3 shifts and lag=2 represents a time difference of 6 shifts. For AW=7, lag1 and lag2 represent a time shift of 7 and 14 shifts, respectively.

In all the figures, the plots show a downwards trend. The highest correlations almost always are at lag 0. The lag effect was examined only for AW 7 and 8 as the correlations are highest for those AW.
The results for 2013 are similar. In conclusion, a time delay (lag) does not affect the correlation.

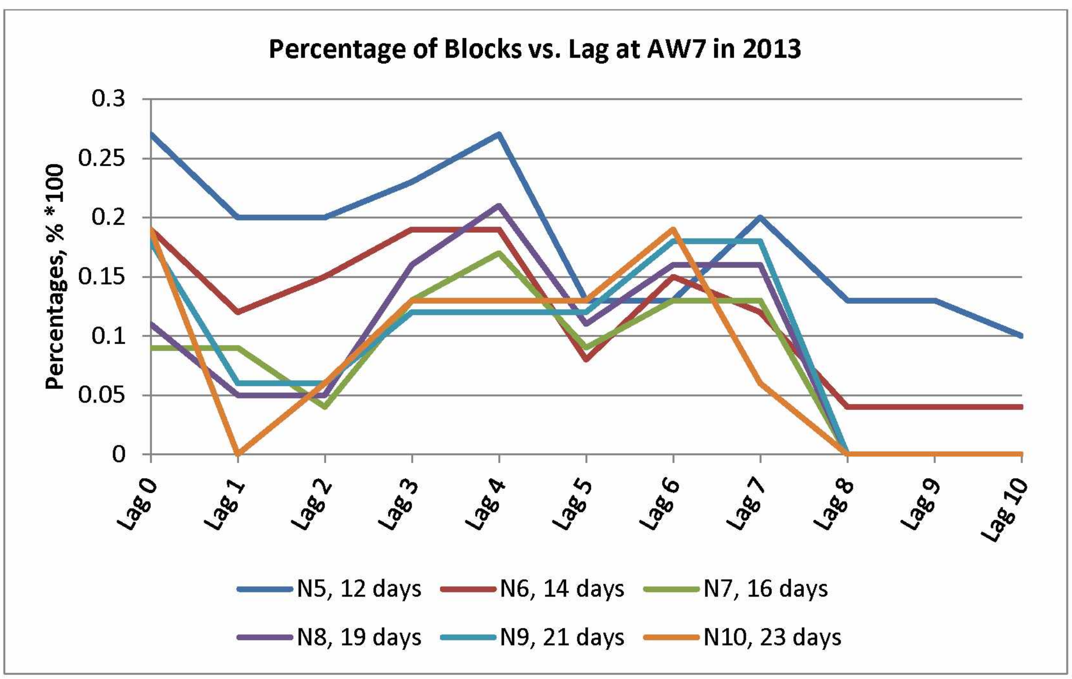

Figure 12. Time lag effect for AW 7 in 2013.

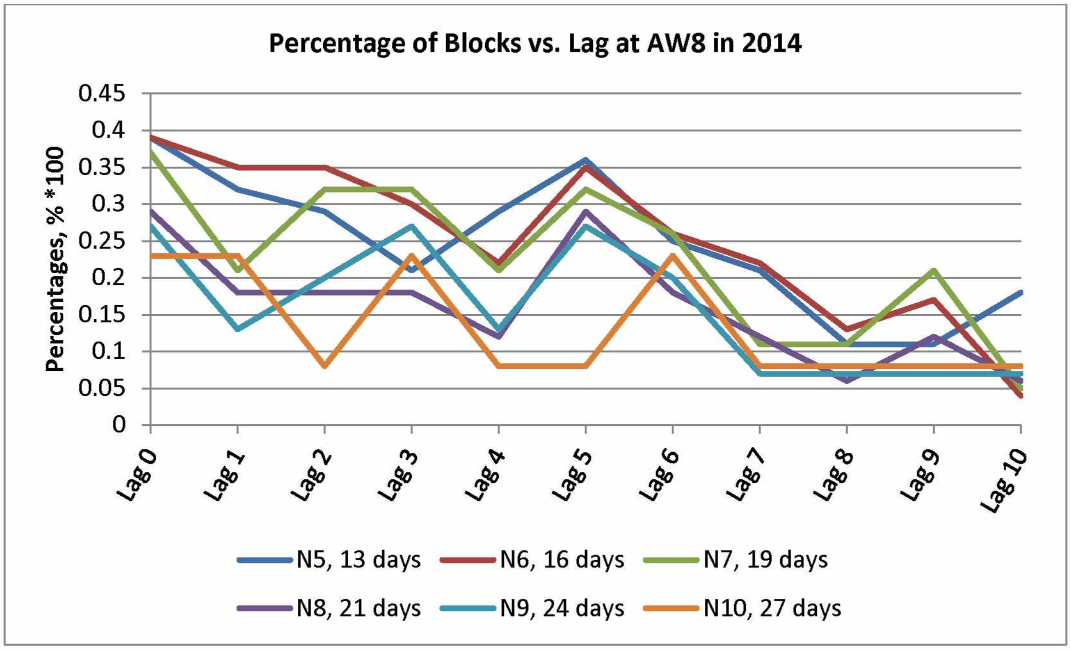

Figure 13. Time lag effect for AW 8 in 2014.

3.5. The operation principle of C&TS

Stockpile #1:

The stockpile capacity totals 65000t and valuable effective capacity is 20000t. These 20000t consistently move while the rest of 45000t pile is considered a dead zone (which moves one time in a month). The valuable effective capacity supplies a mill for one shift. The stacker on the conveyor #3 moves non-constantly along the pile. It is dependent on the fullness of the sections in the stockpile. Conveyors #4 to #8 transport ore in turns. Each shift ore from the mine does not flow simultaneously to the secondary cone crushers from the stockpile #1. See the top of Figure 14.

Stockpile #2:

The ore is screened by screen #17, 18, 19, 20 and 21 after the secondary cone crusher. The 60% (overflow) of total receiving ore goes to the stockpile #2 from the secondary cone crushers #4, 5, 6, 7 and 8, and the rest of the 40% (underflow) is directly transported to Stockpile #3 by conveyor #17. Secondary cone crushers also work in turns. The stacker on the conveyor #11 moves non-constantly along the pile. See the middle portion of Figure 14.

Stockpile #3:

The stockpile receives ore by transportation conveyor #17 from the secondary cone crushers and underflow screens. The total capacity is 135000t and valuable effective capacity is 40000t.
This valuable effective capacity supplies a mill for two shifts. The stacker on conveyor #18 moves non-constantly along the pile; it also depends on the fullness of the sections in the stockpile. The conveyors from #19 to #26 transport ore in turns to the mills. See the bottom of Figure 14.

The material flow as described above justifies the 2-3 shift lag (between the time the mill receives the ore, to the time it finally processes it) detected by the data mining.

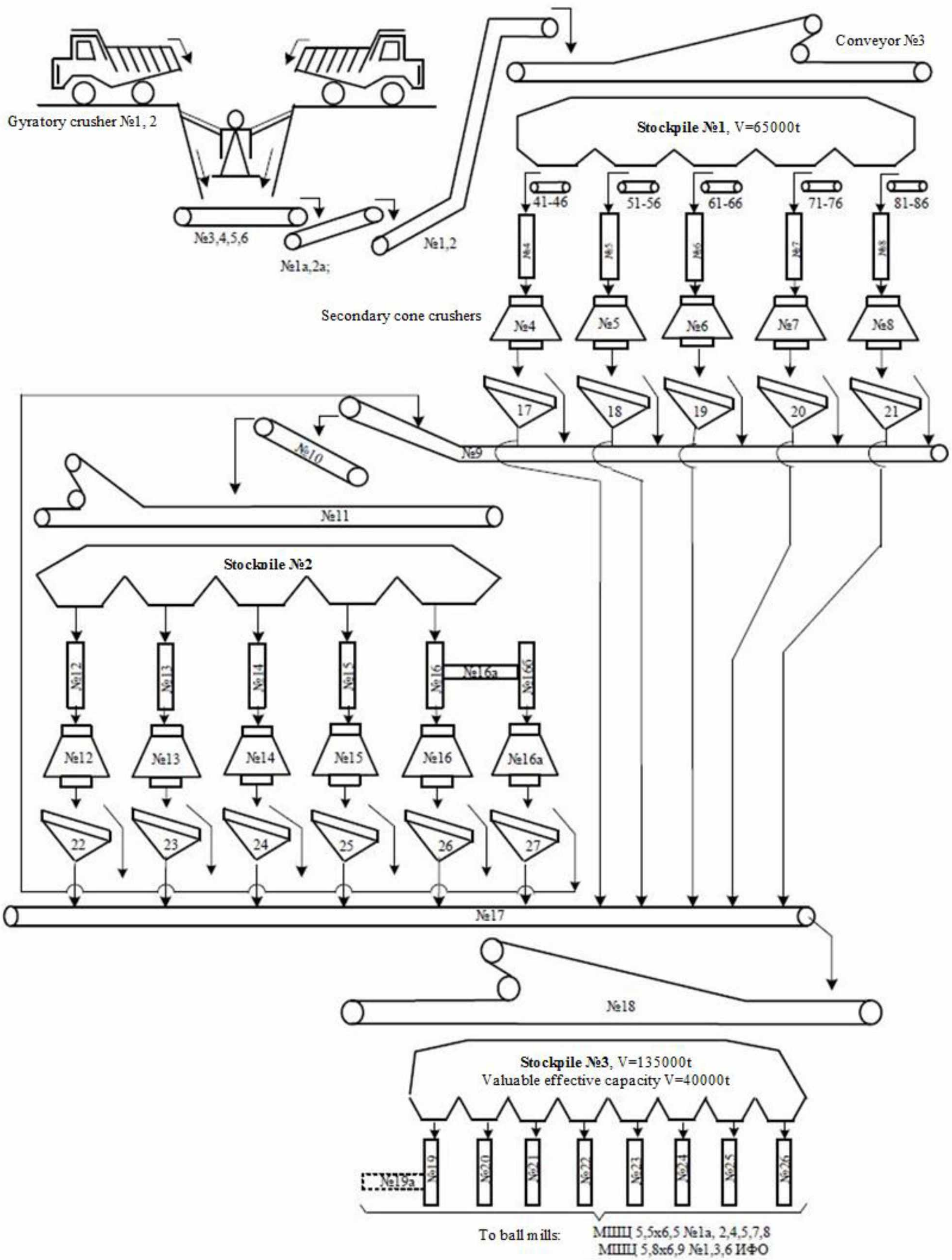

Figure 14. The schema of C&TS of DMPP

4. Summary and Conclusions

A data mining exercise was conducted on mine and mill data at EMC. The production data from mine and mill were first combined and validated before conducting the analysis. A review of annual reports, when compared with production reports, revealed that the mined ore density is likely to be 2.65t/m^3 even though the density is considered to be 2.55t/m^3. This conclusion was also drawn by the initial Feasibility Study of OPM EMC based on a comparison of mined and milled ore data for four years (2011-2014). The density of 2.65t/m^3 was assumed in this project.

According to correlation analysis, the ore does not flow to the mill within the same or next shift. It was determined that one stream of ore progresses through the mill in 7 to 8 shifts (AW7, AW8). This means mine to mill ore is completely processed in a period of 2 to 3 days. The dates of high correlation are somewhat different based on AW.

There does not seem to be a time shift between mined ore and mill ore once the data is aggregated.

Recommendations

Stabilize ore grade in the short of time period needed to reduce one stream of ore flowing time from AW7 and AW8 as much as possible (shift to shift). To accomplish this, the following measures should be taken.

- To control the ore stream into the C&TS.
  - Control the movement of all stackers in each stockpile, and automate the movement of stackers along the stockpiles.
  - Determine ore grade on each stockpile.
  - Determine ore flow speed and traction using the RFID (Radio-frequency identification) magnetic tracker http://www.rftags.co.za/products/oretrak.php

- Modulate the ore stream into the C&TS.
  - Create an exact ore stream model using the controls stated above.

After the measures are taken, the ore stream will be easier to predict and will be easily handled.

5. ACKNOWLEDGEMENTS

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6. Feasibility Study of Open Pit Mine EMC (16.0 million tpy), "Giprotsvetmet", Moscow, 1974

7. Used "Mathlab-R2012b"

Appendix

Table 18-1. Chemical composition of ore (Feasibility Study of OPM EMC (16.0 million tpy), "Giprotsvetmet", Moscow, 1974)

Component	Zone II sulfide		Zone I sulfide
	Sample Jan 1966	Sample Apr 1966	Sample Jan 1965
SiO_2	68.34	68.56	67.36
Al_2O_3	15.62	16.05	15.41
Fe_2O_3	2.42	1.68	3.06
TiO_2	0.67	0.38	-
FeO	0.62	0.76	-
CaO	0.57	0.42	3.08
MgO	0.67	0.14	1.30
Na_2O	2.72	2.30	3.10
K_2O	3.94	2.31	2.68
MnO	0.01	-	0.03
P_2O_5	0.07	-	-
Cu	0.76	1.04	0.14
Mo	0.015	0.007	0.007
p.p.p.	3.16	3.39	3.28

Table 19. Mining conditions of the deposit (Initial Feasibility Study of OPM EMC (16.0 million tpy), "Giprotsvetmet", Moscow, 1974)

physico-mechanical properties of host rocks and ores are given in Table						
Rocks	Density, g/cm3	Porosity, %	Volume weight, g/cm3	Water absorption, %	Wet, %	Strength coefficient on a scale Protodyakonov M.M.
Leached zone						
Granitites	2.6 – 2.7	5 - 11	2.4 – 2.5	-	4.45	5 – 9
Ore	2.6 – 2.7	5 – 11	2.47	-	4.45	to 13
Andesitic porphyries	2.7	8.62 – 12.64	2.4 – 2.6	1.99 – 3.44	2.60 – 5.13	6 – 9
Felsite	2.7	2.56 – 3.59	2.6	0.6 – 0.87	0.62 – 0.65	20
Secondary enrichment zone						
Granitites	2.7 – 2.8	3 – 6	2.5 – 2.7	-	1.95	7 – 16
Ore	2.7 – 2.8	3 – 6	2.5	-	1.95	8 – 12 to 14
Andesitic porphyries	2.84	3.20 – 3.60	2.6 – 2.7	0.64 – 0.69	1.04 – 1.56	12

Table 20-3. High correlation peaks for various AWs in 2013

N5		AW3	AW4	AW5	AW6	AW7	AW8	AW9	AW10	AW11	AW12
		PL5, BC73, PC19, %0.26	PL7, BC52, PC10, %0.19	PL8, BC45, PC9, %0.20	PL10, BC36, PC6, %0.17	PL12, BC30, PC13, %0.43	PL13, BC28, PC10, %0.36	PL15, BC24, PC9, %0.38	PL17, BC21, PC8, %0.38	PL18, BC20, PC5, %0.25	PL20, BC18, PC9, %0.50
Jan	I					'1/8/2013 8:00:00 AM'	'1/9/2013 8:00:00 AM'	'1/4/2013 8:00:00 AM'	'1/4/2013 4:00:00 AM'		'1/5/2013 8:00:00 AM'
	II	'1/11/2013 8:00:00 AM'	'1/13/2013 8:00:00 AM'	'1/11/2013 8:00:00 AM'							
	III	'1/21/2013 8:00:00 AM'				'1/22/2013 8:00:00 AM'		'1/22/2013 8:00:00 AM'	'2/20/2013 8:00:00 AM'	'1/23/2013 8:00:00 AM'	
Feb	I	'2/3/2013 8:00:00 AM'		'2/7/2013 12:00:00 PM'	'2/2/2013 8:00:00 AM'	'2/3/2013 12:00:00 PM'					
	II	'2/20/2013 8:00:00 AM'						'2/15/2013 8:00:00 AM'			
	III		'2/21/2013 12:00:00 PM'		'2/20/2013 8:00:00 AM'		'2/21/2013 12:00:00 PM'				
Mar	I				'3/10/2013 8:00:00 AM'	'3/10/2013 12:00:00 PM'					'3/2/2013 8:00:00 AM'
	II	'3/19/2013 8:00:00 AM'							'3/19/2013 12:00:00 PM'		
	III	'3/28/2013 8:00:00 AM'				'3/31/2013 12:00:00 PM'	'3/25/2013 12:00:00 PM'	'3/29/2013 8:00:00 AM'		'3/30/2013 8:00:00 AM'	'3/30/2013 8:00:00 AM'
Apr	I										
	II					'4/16/2013 8:00:00 AM'	'4/15/2013 8:00:00 AM'				
	III										
May	I	'5/7/2013 8:00:00 AM'	'5/6/2013 4:00:00 AM'	'5/6/2013 8:00:00 AM'						'5/6/2013 12:00:00 PM'	'5/9/2013 8:00:00 AM'
	II		'5/21/2013 8:00:00 AM'				'5/14/2013 4:00:00 AM'	'5/13/2013 8:00:00 AM'			
	III	'5/21/2013 8:00:00 AM'	'5/30/2013 4:00:00 AM'	'5/21/2013 8:00:00 AM'				'5/16/2013 8:00:00 AM'			
Jun	I	'6/7/2013 8:00:00 AM'		'6/2/2013 12:00:00 PM'		'6/4/2013 8:00:00 AM'	'6/5/2013 12:00:00 PM'		'6/3/2013 4:00:00 AM'		'6/6/2013 8:00:00 AM'
	II		'6/14/2013 8:00:00 AM'								
	III	'6/24/2013 8:00:00 AM'									
Jul	I	'7/13/2013 12:00:00 PM'		'7/10/2013 8:00:00 AM'	'7/10/2013 12:00:00 PM'	'7/11/2013 12:00:00 PM'					
	II	'7/19/2013 12:00:00 PM'									
	III	'7/29/2013 12:00:00 PM'									
Aug	I										
	II						'8/15/2013 12:00:00 PM'	'8/16/2013 12:00:00 PM'	'8/14/2013 8:00:00 AM'		'8/15/2013 12:00:00 PM'
	III					'8/24/2013 8:00:00 AM'					
Sep	I		'9/5/2013 8:00:00 AM'								
	II	'9/14/2013 12:00:00 PM'				'9/14/2013 8:00:00 AM'	'9/13/2013 8:00:00 AM'	'9/15/2013 12:00:00 PM'			
	III		'9/22/2013 4:00:00 AM'	'9/23/2013 8:00:00 AM'							
Oct	I				'10/8/2013 12:00:00 PM'	'10/7/2013 4:00:00 AM'	'10/7/2013 8:00:00 AM'		'10/3/2013 8:00:00 AM'	'10/5/2013 12:00:00 PM'	'10/6/2013 12:00:00 PM'
	II	'10/11/2013 12:00:00 PM'	'10/14/2013 12:00:00 PM'						'10/6/2013 4:00:00 AM'		
	III										'10/26/2013 12:00:00 PM'
Nov	I	'11/1/2013 12:00:00 PM'		'11/2/2013 8:00:00 AM'	'11/9/2013 12:00:00 PM'	'11/2/2013 8:00:00 AM'				'11/7/2013 12:00:00 PM'	
	II										'11/19/2013 12:00:00 PM'
	III	'11/22/2013 12:00:00 PM'					'11/29/2013 4:00:00 AM'				
Dec	I	'12/6/2013 12:00:00 PM'	'12/1/2013 12:00:00 PM'	'12/5/2013 4:00:00 AM'		'12/2/2013 4:00:00 AM'		'12/2/2013 12:00:00 PM'	'12/9/2013 12:00:00 PM'		
	II										
	III	'12/26/2013 12:00:00 PM'									

Table 21. High correlation peaks for various AWs in 2014

N5		AW3	AW4	AW5	AW6	AW7	AW8	AW9	AW10	AW11	AW12
		PL5, BC73, PC17, %0.23	PL7, BC52, PC10, %0.19	PL8, BC45, PC9, %0.20	PL10, BC36, PC11, %0.31	PL12, BC30, PC8, %0.27	PL13, BC28, PC11, %0.39	PL15, BC24, PC9, %0.38	PL17, BC21, PC9, %0.43	PL18, BC20, PC6, %0.30	PL20, BC18, PC5, %0.28
Jan	I	'1/4/2014 8:00:00 AM'							'1/8/2014 12:00:00 PM'		
	II	'1/11/2014 8:00:00 AM'									
	III	'1/29/2014 8:00:00 AM'	'1/21/2014 8:00:00 AM'		'1/29/2014 8:00:00 AM'						'1/21/2014 8:00:00 AM'
		'1/30/2014 8:00:00 AM'									
Feb	I					2/7/2014 4:00:00 AM'					
	II	'2/18/2014 8:00:00 AM'		'2/18/2014 4:00:00 AM'							
	III		'2/21/2014 12:00:00 PM'								
Mar	I						'3/9/2014 12:00:00 PM'				
	II	'3/14/2014 8:00:00 AM'				'3/19/2014 8:00:00 AM'					
	III				'3/22/2014 8:00:00 AM'			'3/20/2014 8:00:00 AM'	'3/22/2014 8:00:00 AM'		
Apr	I	'4/3/2014 8:00:00 AM'				'4/9/2014 8:00:00 AM'	'4/10/2014 12:00:00 PM'				
	II	'4/16/2014 8:00:00 AM'	'4/20/2014 4:00:00 AM'	'4/13/2014 12:00:00 PM'	'4/11/2014 8:00:00 AM'			'4/13/2014 8:00:00 AM'		'4/25/2014 12:00:00 PM'	
	III	'4/25/2014 8:00:00 AM'					'4/23/2014 8:00:00 AM'			'4/28/2014 4:00:00 AM'	'4/23/2014 8:00:00 AM'
May	I	'5/4/2014 8:00:00 AM'	'5/2/2014 4:00:00 AM'	'5/1/2014 8:00:00 AM'	'5/3/2014 8:00:00 AM'				'5/8/2014 12:00:00 PM'		
	II	'5/10/2014 8:00:00 AM'	'5/18/2014 4:00:00 AM'	'5/14/2014 4:00:00 AM'	'5/13/2014 8:00:00 AM'						
	III										
Jun	I										
	II	'6/17/2014 8:00:00 AM'		'6/15/2014 8:00:00 AM'	'6/14/2014 8:00:00 AM'					'6/15/2014 8:00:00 AM'	'6/14/2014 8:00:00 AM'
	III	'6/25/2014 8:00:00 AM'				'6/20/2014 4:00:00 AM'		'6/21/2014 8:00:00 AM'	'6/20/2014 8:00:00 AM'		
Jul	I						'7/3/2014 8:00:00 AM'				
							'7/8/2014 4:00:00 AM'				
	II							'7/20/2014 12:00:00 PM'	'7/15/2014 8:00:00 AM'	'7/12/2014 4:00:00 AM'	
	III			'7/25/2014 8:00:00 AM'			'7/30/2014 12:00:00 PM'				
Aug	I					'8/1/2014 12:00:00 PM'					
	II	'8/18/2014 12:00:00 PM'									
	III		'8/28/2014 8:00:00 AM'	'8/29/2014 8:00:00 AM'	'8/27/2014 12:00:00 PM'	'8/29/2014 12:00:00 PM'	'8/25/2014 4:00:00 AM'	'8/22/2014 12:00:00 PM'	'8/27/2014 4:00:00 AM'	'8/22/2014 12:00:00 PM'	
Sep	I										
	II	'9/29/2014 12:00:00 PM'		'9/15/2014 12:00:00 PM'	'9/12/2014 12:00:00 PM'	'9/12/2014 12:00:00 PM'	'9/16/2014 12:00:00 PM'	'9/12/2014 12:00:00 PM'	'9/13/2014 8:00:00 AM'	'9/16/2014 4:00:00 AM'	'9/16/2014 12:00:00 PM'
	III							'9/27/2014 12:00:00 PM'			
Oct	I	'10/10/2014 12:00:00 PM'	'10/7/2014 8:00:00 AM'		'10/10/2014 12:00:00 PM'						
	II						'10/26/2014 12:00:00 PM'				
	III							'10/30/2014 12:00:00 PM'			
Nov	I	'11/7/2014 12:00:00 PM'	'11/3/2014 12:00:00 PM'	'11/2/2014 8:00:00 AM'	'11/3/2014 12:00:00 PM'						
	II						'11/16/2014 8:00:00 AM'	'11/14/2014 12:00:00 PM'	'11/12/2014 8:00:00 AM'		'11/11/2014 12:00:00 PM'
	III		'11/23/2014 12:00:00 PM'		'11/23/2014 12:00:00 PM'	'11/23/2014 8:00:00 AM'					
Dec	I						'12/10/2014 8:00:00 AM'		'12/9/2014 12:00:00 PM'		
	II		'12/19/2014 4:00:00 AM'								
	III										